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THE DISTRIBUTION OF THE STARS

By Professor HARLOW SHAPLEY

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THE distribution of stars is recognized as fundamental in the study of galactic structure. In particular, the problems that are founded on stellar distribution include the relative frequency of various evolutionary stages of stars, the general space density, the superficial density, and the relation of all these properties to distance from the sun and position in the sky. The discoidal form of our stellar system has long been accepted. The changing ideas concerning the dimensions of the system and the interrelation of its various components have not affected the belief that in the direction of the Milky Way the sidereal organization is much more extended than in directions highly inclined to the galactic plane. The discoidal form complicates the analysis of stellar distribution. Still more complicating is the eccentric position of the sun, and the obviously non-homogeneous character of the neighboring parts of the stellar system.

The point that stands out most clearly, after a considerable investigation of stellar distribution, is the restricted value that must be attached to any analysis that does not recognize the heterogeneity of the neighborhood. Some general studies have recently been made in which galactic latitudes were not differentiated, thus ignoring the discoidal form of the stellar system. Many recent studies have failed to differentiate with respect to galactic longitude, thus largely ignoring the sun's eccentric position and the conspicuous clusters and star clouds, some of which are near at hand. I believe that we are on the edge of the great Cygnus star cloud, and that the preferential drift of rapidly moving stars away from the Cygnus region may be an indication and measure of the velocity of that stellar organization with respect to the galactic system and our local cloud. The studies of stellar distribution should recognize clearly that integrated and undifferentiated results refer to a mixture, in

unknown proportions, of the stars of various streams and semi-independent clusters, chief of which is the local system outlined by the brighter B stars.

Equally important, in the analysis of stellar distribution in this neighborhood, are the large obscuring nebulosities in Taurus, Ophiuchus, Sagittarius and elsewhere, most of which appear to be only a few hundred parsecs distant. The great rift in the Milky Way from Aquila southward through Sagittarius has long been recognized as an obscuring cloud; it is near enough to affect seriously the distribution of stars brighter than the tenth magnitude.

Although the lack of homogeneity in the galactic system will seriously disturb attempts to make close analyses of structure and concentration on the basis of general star counts, nevertheless, a study of the numbers of stars of various spectral types and in different galactic regions leads to deductions of interest in the structural problem. The investigation of the spectra of stars during the last thirty years at Harvard has yielded finally the Henry Draper Catalogue, which contains in nine volumes the positions, magnitudes and spectral classes of a little more than 225,000 stars, classified by Miss Annie J. Cannon. The survey covers the whole sky and extends in places to the tenth magnitude and fainter. Indirectly the catalogue is a source for information concerning stellar distances, and therefore can be used to some extent as shown below for the examination of the distribution of stars in space; but it chiefly serves to indicate the distribution on the surface of the sky.[1] A few of the more general results are described in the present account.

The stars have been grouped into eleven general classes. About 99 per cent. of them fall into the familiar classes B, A, F, G, K, and M, which is a series in the order of decreasing surface brightness and also in the order of progressive change in average color from reddish toward blue. It is of interest that about 20,000 of these stars have spectra so nearly identical with that of the sun that no difference could be seen on the small spectrographic dispersions used for faint objects. The most common classes are A and K, especially in the Milky Way, but it must be remembered that this condition refers to the apparent distribution, since the selection of stars for the catalogue is on the basis of apparent brightness rather than

[1] The Henry Draper Catalogue is contained in volumes 91 to 99, inclusive, of the Harvard Annals. Various discussions of the material have appeared since 1921 in Harvard Circulars 226, 229, 230, 239, 240, 245, 248 and in Harvard Bulletins 787, 792, 796. A detailed summary of the investigation of stellar distribution is published in the Proceedings of the American Academy of Arts and Sciences for 1924.

absolute brightness or distance. If we were dealing with a unit of volume rather than a unit of surface we should find, as is well known, a much different condition; instead of the highly luminous giant stars of Classes A and K predominating, we should find that dwarf stars are extremely more numerous than giants. It is also probable that Divisions K and A are long periods in the evolutionary sequence.

Probably one of the most important results of the discussion of the Henry Draper Catalogue relates to this matter of relative numbers in space. We now know the average real brightness of the stars of several spectral classes and also know that the dispersion about the average is small. For such classes the apparent brightness decreases with the distance from the observer, and is, indeed, a valuable measurement of the distance. We find that the highly luminous Class B stars appear in the Henry Draper Catalogue, with apparent magnitudes brighter than 8.25, when at distances up to 880 parsecs (three thousand light years). But dwarf G stars, such as the sun, must be nearer than 70 parsecs to appear brighter than magnitude 8.25. It happens that the number of B's and dwarf G's on the surface of the sky, in the direction of the Milky Way, are nearly the same, although the volume throughout which the former can be seen is nearly two thousand times as great. We therefore conclude that stars in the phase of development of our sun are actually eighteen hundred times as numerous as the highly massive and luminous B stars, which we believe to be in an earlier stage of evolution. In a similar way we find that the youngest of all luminous stars, the giant M's, now appear but once in space for every 350 solar stars. That there are four or five times as many giant M stars as B stars suggests that few have sufficient mass to attain the highest surface temperatures.

The following tabulation gives the surface and space numbers for those classes where the mean absolute magnitudes can be assumed with some certainty. The second column contains the numbers of stars in a hundred square degrees brighter than visual magnitude 8.25 and therefore within the distance limits computed for the third column. The last column gives the number of stars in a million cubic parsecs. Dwarf stars of Classes K and M are likely to be much more numerous than the dwarf G stars.

Spectral Division	Surface Number	Distance Limit	Space Number
Giant M	17.5	430	22
Giant K	69.0	350	160
B	29.7	880	4.4
A	96.9	340	250
Dwarf F	18.7	140	680
Dwarf G	26.0	70	7600

Only the region in low galactic latitudes has been used in the above computation, since in that direction (taking all longitudes together) the change of space density with distance can be ignored in a first approximation. The space explored for the B stars is about 1.5×10^{8} cubic parsecs, indicating that the material used is of considerable weight and better represents this part of the galactic system than the similar analyses based on stars within ten parsecs of the sun.

The fact that most of the stars in this part of the galactic system are in the extreme dwarf stage, suggests that the evolution through known spectral types is chiefly a matter of the past; or much more probably it indicates that the changes proceed more slowly throughout the dwarf series than in the early giant stages of low internal density. The relation of speed of development to mass is also involved in the question. Possibly we have only an indication here that large masses are infrequent, and that average and small masses evolve rapidly in early life. But obviously the observed fact is much more certain than any of these suggested interpretations.

Some of the fainter stars in the catalogue are at distances in excess of 3,000 parsecs; such are the stars of Class B fainter than the eleventh visual magnitude and Cepheid variables fainter than the ninth and tenth magnitude. But as a striking illustration of the small portion of the galactic system to which our spectroscopic studies are limited, we may observe that probably more than 95 per cent. of the stars of all classes and magnitudes in the Henry Draper Catalogue are within 1,000 parsecs of the sun. Only about one millionth of the space known to be closely populated with stars is covered at all well by this extensive compilation of spectra.

It appears, however, that the edges of the stellar system are approached in high galactic latitudes for giant stars of all classes. A distinct concentration to the galactic circle is deduced for the B, A, K, and M stars brighter than visual magnitude 8.25 (the limit of completeness of the catalogue). Stars of Classes F and G, however, are very little concentrated, because they are chiefly dwarfs and only those near at hand, in the region of relatively uniform space density, appear in the catalogue.

Figure 1 illustrates the galactic concentration for the different spectral classes. The ordinates for each diagram are the numbers of stars in a region of one hundred square degrees; the abscissas are galactic latitudes. The diagram illustrates not only the concentration but also, when read vertically, they show the relative frequency of the various spectra in different zones.

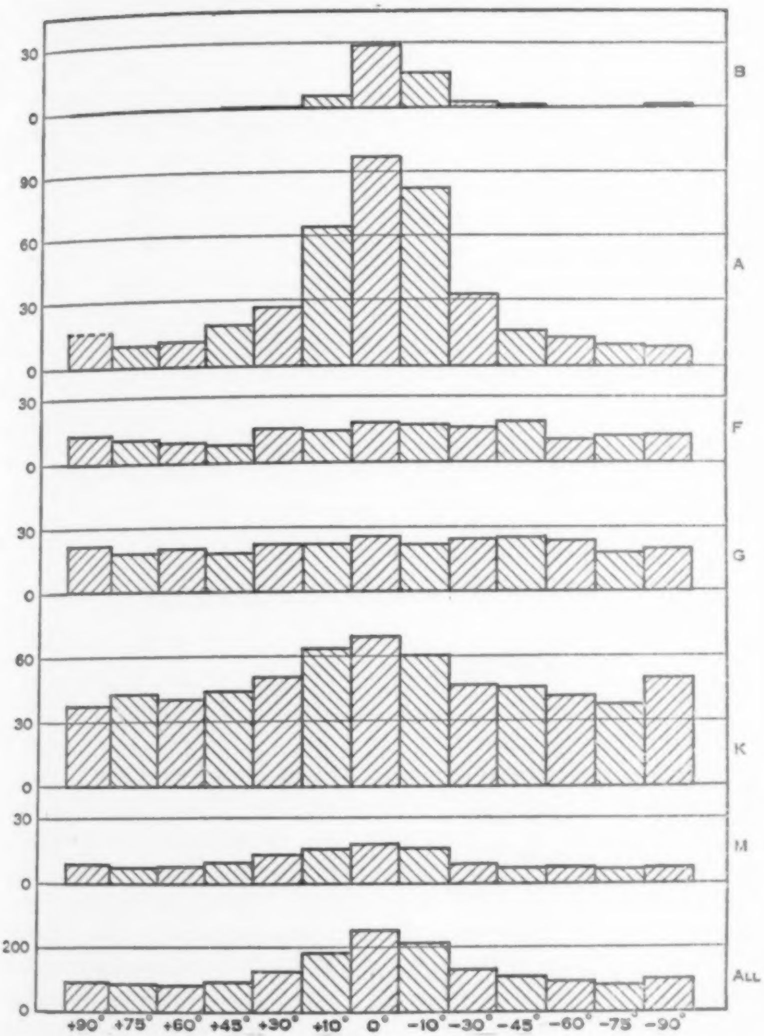

Fig. 1

The most striking feature of Figure 1 is the contrast in galactic concentration between Classes A and F. The former includes subtypes from B8 to A3, and the latter, subtypes from A5 to F2. A closer analysis of the data shows that the rapid change in concentration lies between A0 and A5. This change indicates a very rapid decrease with advancing type in the average absolute brightness of the stars.[2] It suggests that the spectral differences among the early subtypes of Class A may be better regarded as criteria of absolute

[2] Harvard Bulletin 796, 1923.

magnitude than of color and surface temperature. The B stars and early A's are probably concentrated to the galactic plane more than later classes.

In Figure 1 all longitudes were taken together. Figure 2 shows that in different longitudes the A stars brighter than 8.25 differ

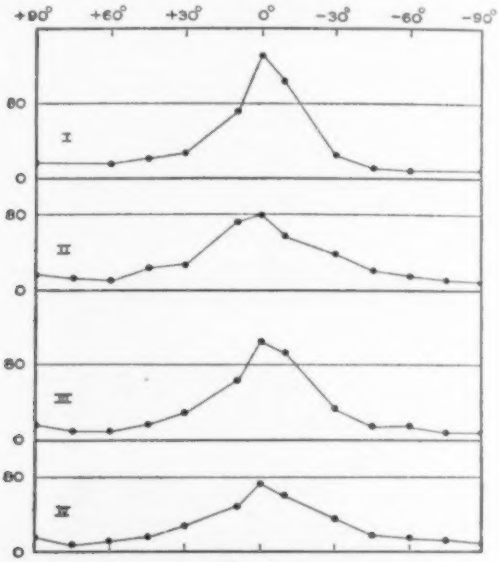

FIG. 2

greatly in galactic concentration. The upper curve shows the concentration in the first quarter of galactic longitude, where the star clouds in Cygnus appear to affect the distribution. The second quarter is affected in low latitudes by the obscuring nebulosities in Taurus and vicinity. The third quarter covers the region of the center of the local system, and the fourth quarter records impressively the influence of the rift in the Milky Way on the distribution of these giant stars of Class A. Since stars brighter than the seventh magnitude also show the rift slightly, we compute that its nearer border may be not more than 200 parsecs distant.

The stars of Class A brighter than magnitude 6.5 are distributed with remarkable uniformity in galactic longitude. The bright B stars, however, show the center of the local system in the constellation Carina. They also indicate clearly that the central plane of the local system is inclined between ten and fifteen degrees to the galactic plane. But the B stars fainter than the eighth magnitude are almost exclusively members of the general galactic system and are highly concentrated to the galactic circle.

When we examine the distribution of the more distant stars, the greater richness of the Sagittarius region is revealed. For instance,

the variable stars of Class M are now recognized as giants at maximum brightness; hence, when the maximum apparent magnitude is faint, they are very remote. They are found to be four times as numerous in the direction of Sagittarius, toward the center of the Galaxy, as in the opposite direction. Similar preference is shown by planetary nebulae, O-type stars, Cepheid variables, the faint B stars and the novae.

The high concentration of faint stars in low galactic latitudes emphasizes the importance of the study of spectra in the Milky Way. Systematic extension of the Henry Draper Catalogue is now being made to fainter stars. But this extension will not attempt to cover the whole sky. Special attention will be given to fields along the Milky Way, particularly those in the northern sky for which the magnitude limit in the catalogue is between eight and nine. In one such field in Aquila Miss Cannon has now recorded 1,567 spectra, of which less than 200 have previously been classified.

CAN THE MASSES RULE THE WORLD?

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No decade in history ever began to witness such momentous changes as those which have occurred since 1914. These changes have been political, economic, cultural and even hygienic, and have been practically world wide. Is there any one dominant trend among all these complex tendencies which have ushered us so suddenly into the new world—for such it is—upon which we look out today? I have long pondered this question, and, as a lifelong student of the deeper currents that control mansoul, have found an answer that seems to me most satisfying, *viz.*, the fundamental impulse that has caused nearly all the troubles of recent years is the growing instinct of revolt against external constraints and control. It is more than kurophobia, or the Freudian resentment against all fatherly authority, and even more than social inhibitions; these are, at most, only its negative manifestations; it is, at root, a new impulse toward spontaneity, self-expression and self-determination, or to live again from within outward. The human spirit is moulting its old carapace, and is beginning to build nobler mansions for itself. Biologically, moulting is a hard process, involving as it does a kind of rebirth, but the new consciousness of freedom it brings is already manifest. Here probably is to be found the best scale by which to measure real progress. Let us, then, specify some salient factors of this impulse of emancipation from outer control.

I

Germany, the most organized country in the world, headed by a monarch more convinced than any in Europe that he was God's vicegerent, feeling its legitimate development impaired from without, sought to break down these barriers by force and extend its sway. In the reaction many crowns fell, the democratic movement became worldwide, and kingcraft in the old hereditary, absolutist sense was found to be either dead or moribund. As I write, twelve countries of Europe, if we include the Sultan, still have royalties at their head. Nearly all of them are intelligent and devoted to making the most and best use of the functions that remain to them; but among them all there is no individual of outstanding ability or power of leadership. In all their political activities they are constrained and directed by ministers far abler than they or by dictators (of whom there are now nine in Europe), who hold all the

power and are above parliaments and independent of constitutions as no king in Europe longer is, and most of whom have none of the prestige of heredity.

There is a pathos about the decadence and passing of the old houses of the Hohenzollerns, Romanoffs and Hapsburgs, and in the present status and prospects of the six to seven hundred personages of royal descent described by F. L. Collins,[1] some of whom are in dire need, and others of whom have subordinate business positions. Moreover, there have long been degenerative processes going on in these families, which are more prone to moral and mental defect than the better families over whom they have reigned.[2] In fact, there are many other conditions in the lives of monarchs that are essentially anti-eugenic, and, although the farewell which even romance, tradition and fashion give them will be a sad one, not only the *Zeitgeist,* but the great Bio-Logos, or spirit of life, has decreed the extinction that the regal function is now undergoing.

We are told that dictatorships mark an ebb in the high tide of democracy. There could be no greater mistake. These dictatorships are simply the crude weapon that the masses, whether civil or military, have seized to batter down opposition to their progress. If popular support should fail, any dictator would lose power in a day. True, in the past dictators have usurped the temporary power delegated to them, have established themselves by force, and have become tyrants. But this is now increasingly difficult, for public opinion and sentiment are more and more dominant throughout the world, and even armies are more and more subject to it. Professional soldiery, always the strong arm of tyrants, has declined, and armies are composed of a citizenry only temporarily under arms for a specific purpose and for a limited time, and hence are more under the control of home opinion and sentiment.

In modern times parliaments, congresses and legislative assemblies of various names, composed of representative delegates elected by the people, have taken the place of and greatly reduced autocratic power, and as a result we have in all progressive lands a vast and growing body of legislation, wise and otherwise, enforced or unenforced, and sometimes covertly or openly defied. This was a great step in the progress of democracy. These bodies have often acquired great power and autonomy, sometimes rivaling and seeking to dominate the executive branch of government, and occasionally defying, or even electing or deposing, its members. But the power of such bodies is limited by the minorities within them, by frequent elec-

[1] "This King Business," 1923, p. 220.

[2] F. A. Woods, "Mental and Moral Heredity in Royalty," New York, 1906, p. 212.

tions, the ever-present regard for coming elections, and also, especially in this country, by powerful lobbies imposing petitions, and by the initiative, referendum and recall, till the old independence and autonomy of members is gone and they are practically reduced to the condition of mere delegates dominated by other forces than their own insight and conviction. They are instructed and restricted, too, by platforms, and bound by party fealty and the dread of defeat and consequent loss of the vast power of patronage, which has nearly quadrupled here within the decade. Here, too, particularly, the old trust in the wisdom of those we send to congress has given place to distrust, and much of the business of the country is anxious and unsettled when congress is in session, while all are confused by the hundreds of new bills introduced every year in not only the national but state legislatures—a single member of the former often introducing scores of new measures and pressing for their consideration.

Distrust of all authority is inherent in all democracies. They rarely recognize real leadership, and have, as Faguet showed, always tended towards the cult of mediocrity, the best man and measures being often rejected for those that are second or third best; while the boss, whom they trust and exalt to power, is one whom they deem represents their own mental and moral level, vaunts himself as the servant of their will, and whom they regard as the protagonist of their own emancipation from all outer constraint.

Thus all political power is to-day, at least, within reach of all. The masses can exercise it themselves, or can delegate it, or any part of it, to whom they choose for a time. And they realize that they can at any time resume and exercise it all by direct or by indirect action. The only form of tyranny in this field that is still possible for them is that of majorities. Not only are all positions open to all, but the vote of the poorest, most ignorant and vicious citizen has the same weight as that of the wisest, best and wealthiest. This ideal of government of, for and by the people is as stupendous and revolutionary as it is novel in the long history of mankind. Indeed, nations and races have been accustomed for so many millennia to being governed by others that they have not yet realized what political freedom means, or their new responsibilities under it, or the dangers it involves; and, least of all, how fundamentally successful self-government of the state rests upon the power and habit of self-control and self-regimentation of individual citizens.

Never were all these considerations more pressingly opportune when we realize that within the decade Germany, most of the Austrian countries and Balkan states and China have become republics;

that the overseas possessions of the British Empire have assumed greater independence—Ireland has become free, and India is fuller than ever of the seething spirit of revolt—and that the king of this great nation, on which the sun never sets, has just had to give his government into the hands of a labor cabinet; while the kings of Italy, Spain, and even the Sultan, have been eclipsed and robbed of all real power by dictators, and that the next decade or two will probably show the world whether or not democracy can be made safe and salutary for the world.

II

The church has lost its old authoritativeness. Two thousand years of the influence of the Prince of Peace did not prevent avowedly Christian nations from flying at each other's throats in a war in which Protestants fought Protestants and Catholics fought Catholics, each side praying to a common God to aid them in slaughtering the other. Only those who can sense the deep and strong psychic currents and their trends in the soul of man can begin to realize how disastrous to ecclesiastical and credal loyalty within Christendom, and how fatal to whatever respect and influence it had upon unbelievers or those of other creeds and races all this has been. The damage to faith thus wrought is only thinly camouflaged by the excellent ameliorative services done by representatives of Christian organizations in the armies.

Again, fundamentalists and anti-evolutionists have not only alienated the intelligentsia from the church, but brought upon it new reproach, if not contempt. The preposterous discussions and schisms about the paternity of a personage born obscurely two millennia ago, the tactless heresy charges and trials, the idiotic interpretations to the effect that the end of the world is at hand, and that Jesus is about to come and sweep to destruction all but the few elect, as the vociferous yellow religionists proclaim—all this suggests not so much ignorant pilotage of the grand old ship of salvation, but the work of scuttlers of it working from within. No higher criticism or aggressive heresy ever began to discredit belief in piety as organized and administered by the church. Despite all the cleverly arranged figures intimating gains, the best of all statistics of the vitality of a religion is actual attendance upon public worship, especially in the Protestant lands, and these show, as we should expect, a very marked relative falling off; while secular activities—the newspapers, movies, games and, in summer, above all, auto trips are fast absorbing the time once given to the church on Sundays. Moreover, reliable results of various investigations also show that with every year of secondary and higher education, the proportion of the rising generation who believe even in the more

fundamental doctrines of a personal God, a future life, miracles, and the inerrant validity of inspired Scripture, diminishes. The time has passed when intelligent and thoughtful men and women will submit their belief or non-belief about the basal problems of life and the conclusions of science to an ecclesiastical visé.

The best thing about this rising tide of dissent is that it is reverent toward true piety, and insists upon religion, rejecting only dogma, the efficacy of rites, the assumption of infallibility and finality, and the monopolization of the way of salvation, which constitute the essence of ecclesiasticism. But, you say, the shamans and whirling dervishes of revivalism still succeed with their incantations:

At the last convention of the International Bible Students' Association at Los Angeles, 30,000 were led by a spell-binding judge to resolve unanimously that "goats" and enemies of the church within it "have with selfish design invaded the schools, colleges, seminaries and universities, with their God-destroying doctrines of higher criticism and evolution," and so forth; that "blaspheming his name" by "a Satan-directed League of Nations" wrought a long list of evils; that "the end of the world has come," and that they should withdraw from the denominational churches as representing Babylon, and so forth.

Doesn't this show an ebb in the tide which runs so strongly away from the church? I answer no, any more than dictatorships in Europe are anti-democratic! The whirlwind exhorter eclipses the pastor for a time, as the dictator does the King. He flouts old formalities, and he wins approval from his hearers because they want a rebirth of a deeper piety, a more direct and unproscribed access to the All-Father, and sympathize with his criticisms of the church, for it is just these "slams" that "get" his hearers. He carries them away with him for a time, but as they are not led into any promised land they soon settle back to their former listlessness because they are not really fed, and only the instinct of revolt is strengthened and remains. Indeed, so far has religious freedom progressed in any intelligent land that almost any one, save only clergymen, can hold and express religious opinions, even the most radical, without prejudice to his economic, social or political standing. All tolerate because all doubt.

III

Gone, too, or fast going, is the old authority of the home. The flapper feels that her mother and all her ideas are antiquated, and she is inaugurating a new type of emancipated young womanhood. We must believe, too, that on the whole her revolt is beneficent. The boy, almost in his infancy, Freudians tell us, or at least long before he knows it, begins to hate and even to feel jealousy toward

his father. Especially do the children of foreign families which land upon our shores—all the more if they speak another language —soon learn to become ashamed of their parents and their ways. The school eclipses the influence of the home, and, as it becomes more and more paternal, of the parents. The homes of the poor, especially in the cities, are less and less attractive to the young. In modern society parents have less and less to do with their children, and thus both discipline and respect have declined.

IV

The "youth movement" is now almost worldwide. When the nations were enlisting men for the great war, and also to hearten those conscripted, they were told that it was a war to end war, to make the world safe for democracy, to usher in a better era. Not only have these promises not been realized, but youth everywhere came home from the war disenchanted. They had learned that, in Sherman's phrase, war was "hell," and their slogan was "never again!" But, worst of all, they found themselves in a world of hunger, poverty, burdened with war debts and their own entire lives in the future dismalized. No wonder, then, that they distrusted the older generation, which they felt was responsible for it. Most of these movements tend back to nature, or at least to a simpler and hardier life. There is little unanimity, but an intense and seething idealism. Some of the traits where the young now go far beyond their elders are an open new diplomacy, internationalism, the reform of the educational system, more democracy, work combined with study and mutual help. Youth is striving toward—to use the slogan and titles of their many little journals that have sprung up everywhere—a new religion, new light, new man, a new age, a new state, new economic relations and peace. In Australia they demand the abolition of armies, navies, forts, submarines and so forth. In the Latin-American countries their efforts are directed toward political and to the most radical educational reform—in France to a new university and a new type of lycée, and so on, in ways we have no time to specify here. The movement is more fully developed in Germany, where most of these movements, of which there are many with diverse ends, hark back to the period before the war of 1870 to that of Goethe, and even to the primitive Germania of Tacitus, although there are counter trends toward Catholicism and even Prussianism. It is least developed in this country, where even in the forty odd student forums it is somewhat exotic, because student life here is so absorbed in extra-curricular activities. In all countries older people look upon it very differently. A few almost apotheosize and others anathematize it. There is one thing, however, in which almost everywhere there is unanimity, and

that is that there must be no more great wars, and it is just at this point where a strike of youth against militarism could have deadly effectiveness. All these forms of protest are expressions of the new spirit of emancipation from authority that is sweeping over the world, and this means a more radical democracy. Everything looks, therefore, to a resumption of authority by the people.

If this is fated, we have to ask what is to become of civilization. If Plato was right in regarding the Demos as a beast, or, if the Le Bon school of thought is right that it means "mobocracy" or "moronarchy," if the war tests that show the average psychological age of our army as thirteen years are correct, do we not have cause for despair? Must we not expect a general *débâcle* of culture? This is the question of questions that confronts us to-day. It seems to many like a relapse from the control of reason to that of instinct, and it is here that pessimism has its stronghold, and some even urge that the democratic ideal is the one great and vital illusion of the modern world.

We believe this is all wrong, and that the people can be trusted. Let us take the broadest possible view, and then I think we shall find hope at the bottom of the Pandora box.

(A) Language, with its wonderful intricacies, its copious vocabularies, its complex but always logical structure, is not a creation of individuals but of the masses of mankind. It was built up slowly from the contributions of innumerable individuals. The same is true of the vast structure of myth and folklore found everywhere. The Zulus had unwritten *mores* which the English in South Africa found so excellent that they substituted them for common law in dealing with crimes against both property and person. The great traditions of races, sometimes dignified by the name of Bibles, were the slow evolutions of races—"Out of the heart of nature rolled the burden of the Bibles old." Durkheim and Levy-Brühl think that groups of primitive men working together bring a kind of afflatus, so that great forward steps are chiefly taken in corrobories, and the apostles of "Proletkult," who would sweep away most of the existing literature and create a new one, think this must be done by joint efforts of mind stimulating mind. The mythopeic faculties have created in their crude forms the very basis out of which all literatures and philosophies sprang, and we are constantly finding new meanings here.

(B) One of the chief reasons why we distrust and underestimate the folksoul is that we do not realize, and indeed have been taught to disbelieve, that it created religions, including all gods and supernal beings of every kind, all heavens and hells and everything else that we falsely call supernatural. There is a sense in which it is true that gods made men, but a larger and older truth is that men

have made their gods in their own images and projected them into the sky. They have had great leaders and religious geniuses who have led them and who have suggested beliefs in all that is transcendent, but the main fact is that it is the acceptance of these suggestions by the masses that gave them all their significance. Thus, when we think we are worshipping God, we are really worshipping the sublimized creation of the soul of mankind which, in this image, has embodied all the best that it has ever been able to conceive. The world needs this insight now as never before, because nothing gives man such confidence in his own intrinsic nature. The common belief that divine beings and events came first is really treason to human nature and fatal to saving faith in it.

(C) All the civilizations of the world, its cultures, its governments, institutions, literatures, science, states, churches and all kinds of organization—these, too, were made by great numbers of men acting together, often for a long period of time and over a wide extent of space. These have decayed or been destroyed over and over, and men have passed through trying periods of *débâcle* and relapse toward barbarism. But mansoul is unconquerable and irrepressible, and it has always sooner or later evolved other forms in all these domains, and best of all there has been general progress. There is often a tendency to ascribe developments that have required centuries of cooperation, conscious and unconscious, to a single man—Homer, Moses, Hamurabi. Sometimes these personages have been purely mythical, and sometimes historic, like Confucius, Buddha, Jesus, Mahomet; but in all these cases the scene was set, the play staged and the leader came, or was fancied to come, embodying the *Zeitgeist* which always produces the right man when needed, just as the chief actors and the play itself in the Attic theater evolved from the chorus. Men do not realize that the power to appreciate a great or good thing and the will to accept it are made warp and woof exactly of the same psychic stuff as is the power to create them, and differs from originality only in degree. We pass to more specific bases of confidence in the masses now so rapidly everywhere coming into power.

(D) Take the Carnegie Hero Fund, which has already given some 1,200 awards, with some 5,000 on their waiting list, to those who have saved the lives of others at the imminent peril of their own. Nearly all these heroes, the majority of whom are young, are from the middle and lower classes, and their acts were unpremeditated, spontaneous and instinctive, showing how altruistic and self-sacrificing gregarious man is at bottom.

(E) Who has not been struck, too, with the fact that on the stage the gallery gods, and in the movies the more popular audiences, always approve every act and sentiment that is noble, and

mete out their disapproval at all character and conduct that is mean and ignoble; and what novelist would dare to violate the imperative demands of his readers that the favorite character should always win the girl, money, fame and every kind of conflict, although the odds sometimes seem to be incredibly against him, while the villain also must get his "comeupance." This shows that human nature is sound to the core when it comes to making fundamental judgments which are always moral.

(F) Woman, too, has very lately everywhere come to the fore, intellectually, socially, in politics and even in business. Her very nature is more altruistic than man's. To borrow the phraseology of the latest and best exponent of her "cause," Madame Lombrosa, she is by nature alterocentric, while man is egocentric. Her interest and her life are in and for others. This is now one of the chief safeguards of the world against the overwhelming self-seeking that marks our era.

(G) Youth, too, which in its generous trends is so akin to the best that is in femininity, is the predominant characteristic of our country, which is young compared with others, not merely in years but in spirit. America is less controlled by its traditions which are few and brief, and has far more regard for the future than is found in any other land. We are generous, and our charities, especially of late, have been unprecedented, because our sympathies have transcended political limits and have become cosmic in their extent.

Finally, if we have a national trait at all comparable with the German *Gemüt* and the French *esprit,* it is common sense, which might almost be called our muse. It may be limited in its scope, but it is the very culmination of sanity. It is the power to judge great things and persons by common every-day standards, to find the key to what is remote in time, space or even race, in what is right about us every day. This, perhaps more than anything else, is the leaven that makes out of all the races and nationalities that have composed our population the true Americanism so often demanded and so often misunderstood.

V

Besides all this, there are certain safeguards which democracy must more and more recognize and make effective. The first of these is eugenics, which is often called the religion of the future. We must give more regard than hitherto to health of body and mind, and to the laws of human stirpiculture. Civilizations of the past have declined because the psychological and physiological laws of breeding were disregarded, and the human stock decayed. Again, education must at every point supplement heredity. From a practical standpoint it is idle to quarrel as to which of these two is the most important; both are essential in democracy. McDougall, who

sees salvation only in eugenics, and H. G. Wells, who insists we must decuple our expenses and equipment for education in order to salvage the race, are partisans. Both these causes must work together in span to make sure of the future, for the breakdown of either means decay.

Finally, I would add that both culminate in the sublimation of love. How far this is achieved or failed of is just now being revealed as the chief factor in human destiny. I believe that the voice of the people is the only authentic voice of the only God there is in the world of men—hence that democracy is the only true theocracy; that men, individually and collectively, were meant to be a law to, and to rule, themselves, rather than to be governed from without; that human nature with all its faults is preponderantly good, and can safely be trusted, because most of its faults and defects are due to repressions by outer authorities which cause arrested development. To-day mankind is reaching its majority, declaring its independence and faring forth on a new Grail quest for real freedom. Instinct and the unconscious are older, better organized, quicker acting and saner than reason or consciousness, somewhat as the lowly life portrayed in "Main Street" and "David Harum" is more truly representative, more interesting and essentially truer to life than are stories of courts and upper-tendom. Indeed, there seems to be a deep impulse beneath and dominating civilization to submit occasionally all its *thun und haben* to the assay of the average man and his saving oracle of common sense. In fact, in a democratic age this is the only tribunal of last resort.

Thus, I have no grave fears of anarchy, bolshevism, scepticism or even of atheism, *Proletkult,* red propaganda, the new woman or the youth movement all of which are so often "viewed with alarm." All these phenomena mean emancipation from old repressions, and a larger liberty. Hegel was right. The best of all measures of human progress is growth and the consciousness of freedom, and this is just as true whether the method of advance be by evolution or by revolution.

On the other hand, we must not forget that democracy in the present meaning of that term is a very new thing in the world. It has, in fact, only just begun, and has a far longer and harder road yet to travel than it has had so far. Hence, its chief assets today are not in its achievements but in its ideals. Most of its beckonings are mirages that never can become real. What is its ultimate goal? I answer that it is a country, state and world in which each individual does what he can do best and is rewarded according to his service. Each will be not only tested from childhood on, but assigned his grade, and be assured the place that allows the freest

scope for doing the best that is in him. We do not begin to realize the difference between individuals outwardly nearly alike.

Some are born to be hewers of wood and drawers of water, and are fortunate if they can be made self-supporting; practical slavery under one name or another must always be their lot. Every civilization has always had and will forever have its drudge class, and no advance in machinery will ever relieve them of their fate, but can only mitigate it. But even they must never be exploited, but enjoy the full reward of all they do, and, above all, should have at every stage of life the door of opportunity kept wide open. Every kind of ability must be dedicated betimes and recognized. So different in gifts are men that if there were to be a Hebraic Jubilee every fifty years, each half century would develop perhaps almost as great inequalities as before. Such a divvy would also give each but a very small portion of what he wants, so that there is always a vast, unsettling and dangerous surplus of unfulfilled wishes. The peril of democracy is that it has aroused so large a body of hopes that are utterly unrealizable. Hence, abhorrent as it is, we must prepare the way for a gospel of renunciation. Most people, at the present time, demand too much of this life, especially now that the belief in another is fading. Ranks and classes are inherent in human nature. Perhaps Goddard's dream will come true, and each must accept the rating that consigns him his true and just place in the hierarchy of the world's work.

Before that comes, however, we must work out the tremendous problems of capital and labor, of the tyranny of majorities, the monopolization of public utilities, and the dethronement of special privileges, especially those that come by inheritance.

The one outstanding trait of the "youth movement," now almost world-wide, is the unification of young intellectuals with labor. This in a generation will make the latter articulate and powerful as never before. Men had to be inspired by extravagant expectations to launch out on the uncharted sea of democracy. Like all dreams, this will have to be reinterpreted, and what they mean found underneath what they say—and these two are very different. But because the human spirit has faced and solved so many other problems, just as difficult if not more so compared with the resources at its command, we believe it will muddle through those that now confront it. We believe this because, and only because, we believe that human nature, however crude, is on the whole still sound at the core. If not, we are lost, and the last great hope of the world will prove its direst delusion.

RECENT DEVELOPMENTS IN PREHISTORY

By Professor GEORGE GRANT MacCURDY

YALE MUSEUM

ONE of the most important developments in the field of Prehistory is the general recognition of the existence in the Upper Tertiary of a human precursor capable of utilizing and chipping flints; this recognition confirms the views held and expressed by the present writer since 1905. Although sufficient evidence on which to reach a positive decision existed at that time, it has taken the discoveries by Reid Moir in East Anglia during the past fifteen years to produce the cumulative effect necessary to convince the more hardy doubters.

Piltdown: Recent investigations and discoveries bearing on human and proto-human skeletal remains are in keeping with the above cited views of the writer concerning the existence of a flint-chipping Pliocene precursor. New light on the man of Piltdown has been furnished by the discovery of additional skeletal material some two miles distant from the original site. It includes a small portion of the occipital, a portion of the right half of the frontal with a part of the orbital margin, and the first (or second) lower left molar. These pieces are in the same chemical condition as the human bones from Piltdown and belong to the same type, even to the relatively great thickness of the cranial wall. In fact, the fragment of the frontal and the tooth might have belonged to the skull and lower jaw from Piltdown, although there is a very slight difference in tooth wear. But the occipital fragment must belong to another cranium, for the same part of the occipital is present in the Piltdown cranium. One can say that these last-found fragments represent at least one additional individual.

If the Piltdown cranium and lower jaw belong to one individual, and if the tooth and cranial fragments from the new site all belong to a second individual, the evidence afforded by the new discovery, although based on small fragments, would confirm, in so far as it goes, Smith Woodward's original conclusion that the Piltdown cranium and lower jaw belong together. It is scarcely within the range of probability that twice in succession an association of fossil human and chimpanzee bones should come to light and that in each case the association should consist of identical parts, namely, the cranium of man and the lower jaw (or rather a tooth from the same) of chimpanzee, unless perchance the new lower left molar belongs to the lower jaw of Piltdown; if this be true, it would

materially strengthen the view that the Piltdown cranium and lower jaw do not belong together. The cranium is everywhere thick and heavy for its size; the same is true of the additional occipital fragment. The lower jaw is of a wholly different type—graceful, shapely, relatively light in comparison with its size.

A radiographic study of the teeth of Piltdown, Heidelberg, Krapina, Ehringsdorf and modern man as compared with the teeth of the higher apes, supports the view that the teeth of the Piltdown lower jaw are human and not ape-like. In man, both fossil and living, and in Piltdown, the pulp cavities are relatively much larger than in the higher apes. The crown height of the Piltdown teeth is comparable with that of fossil man and considerably greater than that of the chimpanzee. Thus, the Piltdown dentition is to be classed in this respect with that of *Homo heidelbergensis*, *H. neandertalensis*, and even with that of recent man, all of which are hypsodont, rather than with the low-crowned or chamaedont dentition of the chimpanzee. It is possible that the Piltdown jaw represents an older type of man than do the two Piltdown crania.

The latest reconstruction of the Piltdown skull by Elliot Smith and John Hunter has brought to light additional primitive cranial characters that are in keeping with evidence furnished by the discovery of the second individual and with the assumption that cranium and lower jaw belong together. They find that the occiput is much shorter than was originally supposed to be the case. This brings the cranium more in keeping with the lower jaw in so far as type is concerned and gives a cranial capacity not exceeding 1,260 cubic centimeters.

All the new evidence seems to point in one direction, the one which would lead to a correlation of cranium with lower jaw. The cranium is human but belongs to a primitive type hitherto unknown, wholly different from the Neandertal type and even the Heidelberg type. The lower jaw is ape-like but not necessarily that of an ape; although more primitive than the cranium, the association of the two, if not based on positive data, is at least not an anatomic impossibility. There is also ground for referring the jaw to an earlier and more primitive type than the crania.

It was the author's good fortune to examine the original Piltdown specimens in 1922. In the exhibition room of the South Kensington Museum, Smith Woodward had placed on view a cast of the lower jaw (right half) fitted to the left half of the lower jaw of a chimpanzee. The author noted that the outer line of symphysial contact was longer on the Piltdown half than on the chimpanzee half, although the two rami were approximately identical in size. This means that the post-symphysial platform is even more

pronounced in the Piltdown lower jaw than in the chimpanzee. In order to surmount such an anatomical obstacle, one must invoke a wider range of individual variation within the genus *Homo* (*Eoanthropus* included) than has hitherto been considered ample.

One can not accept the association of cranium and lower jaw and still remain skeptical regarding the association of the canine tooth with the lower jaw. The second discovery did not include a canine tooth. The Piltdown canine was found later, but at a spot near where the lower jaw had been found. It is more ape-like than the molars and is the only canine thus far discovered. Its right to a place in the dentition of the man of Piltdown comes partly through the exaggerated chimpanzee slope in the symphysial region of the lower jaw and partly through default of other claimants. This right would most certainly be questioned should another less ape-like canine be found at Piltdown.

Pithecanthropus erectus: Further researches into the nature of the remains of *Pithecanthropus erectus* found by Dubois at Trinil, Java, tend to confirm the view that a human precursor capable of utilizing and chipping flints might well have existed as long ago as the Upper Tertiary. Although the *Pithecanthropus* remains were for a time inaccessible to anthropologists, Dubois has continued his studies, especially of the endocranial surface of the skull cap. He finds it to be perfectly preserved; the region of the Broca convolution, the seat of articulate speech, is quite different from that in any known ape's brain. The making of an endocranial cast has enabled Dubois to revise his estimate of the cranial capacity which he now places at 985 cubic centimeters (instead of 850 cc), a figure slightly larger than the minimum (960 cc) among the Veddahs and much larger than the cranial capacity of the adult male gorilla (550 cc). *Pithecanthropus erectus* is, therefore, much nearer to *Homo* than was at first supposed. Both Hrdlička and McGregor, who were so fortunate as to see the originals last summer, would place *Pithecanthropus* much nearer to man than to any known ape. The fragment of a lower jaw with the first (or second) premolar and the socket for the tooth immediately in front was found in the same horizon as *Pithecanthropus,* but at a distance of some 40 kilometers (25 miles) southeast of the Trinil site; judging from its appearance, this fragment might well have belonged to another individual of the same genus.

Ehringsdorf: To the adult human lower jaw found in travertine interglacial deposits at Ehringsdorf near Weimar in 1914 there has been added the fragmentary skeleton of a child ten years old, including the lower jaw. The latter has points in common with the lower jaw of the adult, such as absence of chin and a sort

of post-symphysial platform. The ascending ramus which is present in this child resembles the Piltdown lower jaw more closely than it does that of Mauer. The Ehringsdorf human skeletal remains were found associated with flint artifacts and a warm fauna; they are older than the remains of Neandertal man associated with a cold fauna.

La Quina: Dr. Henry Martin's discovery of the cranium of a Mousterian, or Neandertal, child about eight years old in the rock shelter of La Quina (Charente) has added appreciably to our knowledge of Neandertal racial characters. The cranium is nearly complete and shows very clearly the rudiments of all the special characters that appear in the adult; dolichocephaly, low forehead with frontal protuberances, prominent brow ridges which span without a break the space above the root of the nose, diminutive mastoid processes, and big round orbits. Happily, the framework of the nose is complete, showing that the Neandertal nose was not so flat as some had been led to believe. This cranium of a child differs enormously from the cranium of an eight-year-old *Homo sapiens* and indicates that Neandertal cranial morphology is very old as well as specific in character.

Solutré: The type station of the Solutrean Epoch also contains an Aurignacian horizon; in this horizon, at the classic station of Crot-du-Charnier, a discovery of capital importance was made in 1923 by Drs. Mayet, Arcelin and Depéret, who uncovered three Aurignacian burials *in situ* beneath the horse magma. The bodies had been left in extended position with the head in each case to the west. Near the first burial, that of a young adult female, there were found the fragmentary skeletons of two very young children. Burial Number 2 was that of an adult male, as was likewise that of Number 3. The three formed a linear series running east and west; in each case two stones had been placed at the head (one on either side).

A detailed study of the three adult skeletons is being made by Dr. Lucien Mayet, of the University of Lyons. The two males were tall—1.83 and 1.75 meters (6 feet and 5 feet 10.5 inches), respectively; their skulls have a cephalic index almost too large to bring them within the dolichocephalic class. They are said to be more like the man of Cro-Magnon than that of Combe-Capelle. The stature of the female is estimated at 1.55 meters (5 feet 1 inch). Some of the sepultures found in the Crot-du-Charnier at an earlier date were no doubt of Aurignacian age as had been stated by Obermaier.

Cultural Evolution

Switzerland: There have also been important developments in the field of cultural evolution. A recent discovery proves that inter-

glacial man was able to support himself at great elevations in the Swiss Alps. Emil Bächler has discovered a cavern at a height of 2,445 meters (7,946 feet), near the top of Drachenberg, southerly from Ragatz. This cavern, very appropriately named *Drachenloch,* is in the heart of the Alpine field of glaciation; it contains not only human cultural remains but also fossil animal remains. The nature of these is such as to preclude the possibility of their being post-glacial; they must therefore be referred to the last interglacial (Riss-Würm) epoch. The abundance of cave bear remains (averaging more than 95 per cent. of all the fossil animal remains) in Drachenloch is an interesting phenomenon and no doubt due to the fact that the interglacial hunter brought his favorite game animals there as booty. The bones are never in anatomic relation; they are not water worn, hence could not have been washed in, and the deposits are not due to water action.

The Cult of the Cave Bear must have held sway at Drachenloch. Bächler found altars on which skulls and long bones of the cave bear were placed in orderly fashion; the skulls were oriented so as to face the cavern entrance (also exit since it is a blind cavern). This proves that something akin to the religious instinct was already developed long before the cave-art period and the appearance of the early Cro-Magnons in western Europe; it even antedates the Neandertal race associated with a cold fauna.

The Drachenloch hunter improvised a bone tool consisting of a cave-bear fibula for skinning and preparing the hides of the cave bear. The bone was broken obliquely near the center and the broken surface was polished for and by use; the proximal epiphysis was employed as the handle. Bächler found 31 specimens arranged on a flat stone so as to bring the handle always at the same end of the pile; some of these specimens had clearly seen service as indicated by the wearing down of the broken end. Distal ends of the fibula were also found, but none of them showed marks of use; the distal epiphysis obviously did not fit the hand so well as the proximal. Bone splinters and canines of the bear, split longitudinally, were utilized as pointed implements.

The innominate bone of the cave bear was made to serve a variety of uses through the removal of the distal ends of the iliac, pubic and ischiac portions; the margins often bear marks of use. Such tools admit of service in a number of ways: as a skin scraper, or as a vessel for holding water, blood or oil (lamp). Specimens of this sort occur by the hundreds at Drachenloch, as many as 25 or 30 having been found in a single heap.

Siberia: New light has been shed on the character and geographic distribution of Upper Paleolithic culture by Gero von

Merhart's discoveries in the loess of the Yenisei valley, Siberia. The sites explored by von Merhart are in the vicinity of and to the south of Krasnoyarsk. They, as well as the previously known station of Afontova, belong to the Upper Paleolithic (probably Magdalenian) with a Siberian facies.[1] Similar finds have been reported from Wercholensk Mountain near Irkutsk by B. E. Petri, and from China by Father Teilhard de Chardin.

France: One of the most active of the cave explorers in France is Dr. R. de Saint-Périer. For the past dozen years he has explored a group of caves (grotte des Harpons, grotte des Boeufs, grotte des Rideaux) at Lespugue between Saint-Gaudens and Saint-Martory (Haute-Garonne). All three of these caves have yielded portable examples of Paleolithic art as well as artifacts: engravings of the horse on bone, harpoons of reindeer horn, a stone lamp, etc., from the grotte des Harpons; bone javelin points, bone needles, baton, engravings on bone, and a fish (probably flounder) in bone with the contours cut away, from the grotte des Boeufs; bone javelin points, flint implements, and an ivory statuette of a human female (Venus) from the grotte des Rideaux. This last is of special importance because practically complete, of fine workmanship, and of a type especially favored by Aurignacian artists. Statuettes and relief figures of the same general type had been found previously at Brassempouy (Landes), Laussel (Dordogne), the Mentone caves, and Willendorf (Lower Austria); while in 1922, Dr. Otto Schmidtgen found the lower half of two female statuettes of this type in the loess within the city limits of Mainz on the Rhine.

The ivory statuette from Lespugue surpasses in length any other one of the group, although by no means as large as the reliefs from Laussel. It has the characters common to all—undifferentiated features, large pendant breasts and mountain of Venus, enormous hips, large thighs, slender arms, and legs diminishing from the knee down—but resembles the Venus of Willendorf more closely than any other. Unfortunately, the pick of the workman injured the statuette in the region of the breasts; the restoration serves to emphasize the close resemblance to the Willendorf specimen. The pose is exactly the same even to the resting of the lower arms on the breasts and the outlines tapering from the hips in both directions. They are as much alike as a tall slender figure can be like a short stocky figure of the same general type. The artists who made them were both masters of the same canons and traditions. The striking similarity of these two figures throws a flood of new light on the homogeneity of Aurignacian culture over a wide geographic area. If specimens of this kind can still be found in the caves of the Dor-

[1] *Amer. Anthropol.*, N. S., XXV, 1–55, 1923.

dogne and Garonne valleys, the caves of Grimaldi, and in loess of the Danube and Rhine valleys, the probabilities are that they once existed at all the principal Aurignacian settlements in central and western Europe.

During the summer of 1923 the region between Saint-Gaudens and Saint-Martory was made to yield more of its cave-art secrets. A prediction made by the present writer in 1913 after Count Begouen's discovery of bisons modeled in clay at Tuc d'Audoubert (Ariège), that such figures were common to many Paleolithic caverns but had been destroyed, was literally verified last summer by Norbert Casteret's discovery of many animal figures modeled in clay in the cavern of Montespan (Haute-Garonne). Chief among these is a large headless bear, 1.10 meters (43.3 in.) long; the presence of a bear's skull between the forepaws of the model leads Casterest to conclude that the latter might have been provided with a real bear's head. The body is covered with dart thrusts. Around the bear were some twenty smaller clay models in relief rendered unrecognizable by the action of dripping water; the three best preserved are horses with ample paunches and abundant mane and beard. Elsewhere there were three large feline figures (1.50–1.60 meters) leaning against the wall and much damaged; the breast of one is marked by numerous javelin thrusts. A horse's head in clay about the size of a man's hand was discovered in the same gallery. On a bank of clay Casteret found half of a woman's body modeled in clay, also several clay balls.

That the artist purposely mutilated some of the models by means of numerous dart stabs is a performance full of magic significance. It seems that the Montespan clay models were never so perfectly formed as were the bisons from Tuc d'Audoubert; the latter were chosen apparently to live for breeding purposes, while those from Montespan were marked for death at the hands of the hunter. No text could be more eloquent of the true meaning of cave art than these mute but by no means inglorious witnesses from Tuc and Montespan, testifying to the caveman's need for clothing and sustenance, and to the magic means invoked in his behalf.

In addition to the clay models, Casteret found at Montespan mural engravings of the bison, horse, reindeer, stag, ass, wild goat, mammoth and hyena; the horse and bison predominate. There were also engravings done in the clay of the cavern; those above high water are still preserved.

Casteret deserves high praise for the courage and skill exhibited in meeting difficulties. The danger of losing one's way, even where there is no water to wade or swim, would suffice to discourage many. Casteret had not only to swim, but also dared to pass through the neck of a siphon under water; for the ceiling was so low at one place as to be completely submerged. The story of how he alone, in

bathing attire and carrying a candle and matches in a rubber case, swam a subterranean stream for 1,190 meters (ca. 3,900 ft.) to be finally rewarded by his notable discoveries at Montespan, is a striking example of the courage and endurance demanded of those who would wrest from the caverns their subterranean secrets. In this class belong the achievements of Count Begouen and his sons at Tuc and Trois-Frères (Casteret is a student of Count Begouen at Toulouse) and the Abbé Lemozi with the youthful David at the cavern of David in Lot.

In 1922, David, a boy of fourteen, inspired by the discoveries of the Abbé Lemozi at Marcenac, Sainte-Eulalie and Murat, decided to do some exploring on his own account. Armed with a candle and matches, the lad began exploring on his father's own land; he squeezed through an aperture, crept into a small gallery, and after unusual difficulties eventually found himself in another gallery of large dimensions. Much excited by his success, the lad climbed back to sunlight and reported his discovery first to his father and then to the Abbé Lemozi. Within a month the Abbé Lemozi and David found on the walls of the large gallery some forty figures engraved or painted in black and red; bison, mammoths, horse, fish and the human hand. The great gallery is connected with two smaller galleries, one of which contains a beautiful mural figure of a bear; the other contains mural engravings and paintings, bones and fossilized excrement of the bear. Of special significance are the engraved figures of men (ithyphallic) followed by women with prominent pendant breasts. The art in the cavern of David has been referred in part to the Aurignacian and in part to the Magdalenian Epoch.

It can thus be seen that recent discoveries have tended to widen the field of Paleolithic art. Enough is now known to give one a fairly good idea of the cave artist's reaction to the world about him and the reasons for his choosing the models he did. Almost all his models were animals; representations of plants are very rare and those of inanimate objects also rare. An overwhelming majority of the animals were chosen from among the vertebrates, preference being given to mammals that were useful for food and otherwise: the horse, red deer, reindeer, bison, mammoth, etc. Representations of invertebrates, so far as known, can be counted on the fingers of one hand. The fifth example, an ivory coleopter (insect) from the grotte du Coléoptère (Luxembourg), Belgium, has just been reported by J. Hamal-Nandrin. The four examples previously known are all from France: a coleopter of lignite from a cave at Arcy-sur-cure (Yonne), an ivory beetle from Cap Blanc (Dordogne), a ladybug from Laugerie-Basse (Dordogne), and a *Cypraea* shell of ivory from the cave of Pair-non-Pair (Gironde).

THE HISTORICAL BACKGROUND AND SETTING OF THE PHILOSOPHY OF FRANCIS BACON[1]

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I. Introduction

In a paper prepared for the Toronto meeting of the American Association for the Advancement of Science the writer attempted to catalogue the various intellectual influences which combined to bring about the decline of ancient science.[2] It was there suggested that an altogether different set of cultural factors and psychic attitudes was required before any reasonable hope could be entertained of the possible rise of an ardent interest in experimental and observational science. It will be the purpose of this paper briefly to survey the historical factors which conditioned and produced these novel intellectual attitudes and made the era of Francis Bacon one of the most dynamic and interesting in the history of thought, science and culture, thus rendering Bacon's enthusiastic manifesto of the inductive and observational method singularly appropriate to his age, whatever his deficiencies in recognizing certain phases of the scientific achievements of his contemporaries, who were as much less gifted stylistically as they were more talented in the actual work of the scientist.[3]

II. The Scholastic Synthesis

As Bacon's "Novum Organon" was designed to uproot and supplant the "Organon" of Aristotle, our survey of the background of Baconian thought should begin with a brief analysis of the Scholastic method, as systematized by Aquinas, Scotus and Occam, which presented the most perfect embodiment of dialectical technique and skill yet produced by mankind. The Patristic age, profoundly influenced in its intellectual attitudes by Neo-Platonism, had eschewed reason and placed its reliance upon faith, revelation and authority.[4] Perhaps the first important thinker to challenge this view of the all-sufficiency of faith was the most daring mind of the ninth cen-

[1] Paper read at the Cincinnati meeting of the American Association for the Advancement of Science, December 31, 1923.

[2] Published in the *Pedagogical Seminary*, June, 1922.

[3] The best guide for such a survey is J. H. Robinson's "Outline of the History of the Western European Mind," pp. 28–51.

[4] A. Harnack, "History of Dogma," Vol. I, pp. 336 ff.

tury, Erigena, who suggested that in certain cases reason might occupy an important place along with faith in unravelling the mysteries of theological verity. This position was not general, however, at the time, and it brought no little unpopularity and criticism upon its author and sponsor.[5] Much more in the spirit of the age were the edifying encyclopedia of Rhabanus Maurus, embodying accepted tradition as to secular and spiritual truth, and the convenient *Glossae* of scriptural and patristic authorities on various problems of theological import prepared by men like Walafrid Strabo.[6]

This practice of compiling edifying and convenient anthologies of accepted authorities went along very well and seemed adequate for the guidance of the faithful Christian on his itinerary to the New Jerusalem, until, in the early twelfth century, a monk named Peter Abelard brought out a work entitled "Sic et Non," which proved that revealed authority was apparently frail and untrustworthy. He selected certain main problems of philosophy and theology, and then indicated that on all these issues there were fundamental divergences of opinion on the part of the most eminent and reputable of scriptural and patristic authorities. He also launched a vigorous attack upon the Neo-Platonic and Patristic contention that credulity was the mental attitude most befitting a Christian. In what might well be the slogan of every critical and progressive thinker, he denied the efficacy of simple and gullible credulity and passive expectation of revelation, by holding that "the beginning of wisdom is found in doubting; by doubting we come to examine, and by further examination we may come upon the truth." By his subtle dialectic he indicated the power of reason in the face of the futility of discrepant authority and dubious revelation.[7]

After the time of Abelard the question raised by Erigena as to whether reason might not have a place along with faith was an anachronism; it was thenceforth evident enough that faith could no longer rest on authority and revelation alone, but must be buttressed by the most irreproachable logic. Such being the case, it was essential to provide some place in which the defenders and expositors of the faith might be adequately trained for their new requirements and responsibilities. The result was the rise of the medieval universities. The scope and purpose of medieval university instruction is well expressed in the famous medieval phrase that "the sword of God's word is forged by grammar, sharpened

5 R. L. Poole, "Illustrations of the History of Medieval Thought."

6 H. O. Taylor, "The Medieval Mind," Chap. X.

7 J. McCabe, "Abelard"; J. G. Compayré, "Abelard and the Rise of the Universities."

by logic, and burnished by rhetoric, but only theology can use it." While there were universities which offered graduate instruction in law and medicine, theology still remained "the queen of the sciences," though the students of theology were not as numerous as they became after the Counter-Reformation. The work for the bachelor of arts degree was regarded as little more than an academic apprenticeship, and the subjects studied were primarily the trivium, or first triad of the seven liberal arts, consisting of grammar, rhetoric and dialectic. The latter was the most important, however, and it prepared the student to go forward to advanced work in law and medicine as well as theology. It was based primarily upon Aristotle's "Organon" and was the dominant technique of medieval Scholasticism. It rested upon the assumption that the realm of reality was the world of ideas, generally independent of the external world as revealed by sense perception, and that truth could be assuredly surprised and captured when pursued by a strategic ruse founded upon the laws of sound argumentation. Avoidance of logical fallacies in weighing the arguments of the ancients, rather than observation of the commonplace things of nature, was the sure path to determinate truth and the augmentation of wisdom.[8] Francis Bacon himself thus caustically summarized the methodology and achievements of the Scholastic philosophers:[9]

> Having sharp and strong wits, and abundance of leisure, and small variety of reading, but their wits being shut up in the cells of a few authors (chiefly Aristotle their dictator), as their persons were shut up in the cells of monasteries and colleges, and knowing little history, either of nature or time, they did out of no great quantity of matter and infinite agitation of wit spin out unto us those laborious webs of learning which are extant in their books.

The following passage may be spurious, but no one acquainted with medieval learning would regard it as an inaccurate representation of the procedure of the Scholastic age in the settlement of a perplexing problem:

> In the year of our Lord 1432, there arose a grievous quarrel among the brethren over the number of teeth in the mouth of a horse. For thirteen days the disputation raged without ceasing. All the ancient books and chronicles were fetched out, and wonderful and ponderous erudition, such as was never before heard of in this region, was made manifest. At the beginning of the fourteenth day, a youthful friar of goodly bearing asked his learned superiors for permission to add a word, and straightway, to the wonderment of the disputants whose deep wisdom he sore vexed, he beseeched them to unbend in a

[8] C. H. Haskins, "The Rise of Universities"; H. Rashdall, "The Universities of Europe in the Middle Ages"; L. J. Paetow, "The Arts Course in Medieval Universities"; M. DeWolf, "History of Medieval Philosophy."

[9] Cited in J. H. Robinson, "Mind in the Making," p. 122.

manner coarse and unheard of, and to look in the open mouth of a horse and find answer to their questionings. At this, their dignity being grievously hurt, they waxed exceedingly wroth; and joining in a mighty uproar, they flew upon him and smote him hip and thigh, and cast him out forthwith. For, said they, surely Satan hath tempted this bold neophyte to declare unholy and unheard of ways of finding truth contrary to all the teachings of the fathers. After many days more of grievous strife the dove of peace sat on the assembly, and they as one man, declaring the problem to be an everlasting mystery because of a grievous dearth of historical and theological evidence thereof, so ordered the same writ down.

Yet it is easy to be over-critical, supercilious and contemptuous in estimating the intellectual attainments and contributions of the Schoolmen. Considering the cultural and intellectual setting of the time, they were a credit to scholarship and the teaching profession. They aroused a permanent professional interest in teaching, outlined and systematized the knowledge requisite for the profession, perfected the technique of research as that matter was then understood, and generated real enthusiasm on the part of a multitude of students who were compelled to study under far less advantageous conditions than now exist in institutions of higher learning. For the greater part of the intellectual life which existed in the medieval period the scholastic philosophers and pedagogues were responsible, and the superiorities of modern university instruction and scholarly achievement must be assigned primarily to the vast advances in the general cultural and technical setting of modern educational efforts.[10]

III. Progressive Intellectual and Scientific Trends in the Medieval Period

Two other facts which should lead us to take a somewhat more appreciative standpoint towards the Middle Ages than is frequently done are the existence of men whose attitudes were a harbinger of the coming era of observational and experimental science; and the western European appropriation of the learning which the Arabs had absorbed from their contact with late Hellenistic culture and the East, and preserved in part throughout the medieval period. Men like Adelard of Bath, Michael Scot, Albert the Great, Peter of Abano and Witelo were truly scientific in their attitudes and aspirations, and might well have been great laboratory scientists had they lived in the scientific and technical setting of Helmholtz, Pasteur

[10] A fairly judicious estimate is to be found in Taylor, "Medieval Mind," Vol. II, Book VII. The best summary is contained in Haskins, *op. cit.*, chap. ii.

[11] See Lynn Thorndike, "History of Magic and Experimental Science during the First Thirteen Centuries of Our Era"; Vol. II, pp. 14–49, 307–337, 454–456, 517–575, 874–947; and C. H. Haskins, "Studies in the History of Medieval Science."

and Emil Fischer.[11] The venerable illusion that Roger Bacon was the only medieval figure who comprehended or practiced the elements of the observational and inductive method should have been dispelled by the various critical and historical essays which appeared around the year 1914, in conection with the seven hundredth anniversary of Bacon's birth, and is no longer at all tenable in the light of the recently published researches of Professors Lynn Thorndike and C. H. Haskins on the scientific activity of the medieval period.[12] Yet, if Bacon was not unique in regard to his actual achievements in the field of scientific activity, it will probably be conceded by even critical students that he set forth the limitations of the dialectical method, discussed as a methodological abstraction and technique the observational and experimental method, indicated the possible technical and social improvement inhering in the application of science, and classified the leading causes of obstruction to clear and independent thinking more successfully than any other single figure in the Middle Ages. At the same time it is not unfair to point out that his preeminence, if it may be regarded as such, like that of Lord Bacon, consisted more in his superior rhetoric and the more trenchant phraseology of his writings than in substantial practical achievement in scientific activity.[13]

Even more important for the intellectual and scientific progress of Europe were the series of innovations in mathematics and science, and the significant practical inventions which came into western Europe before the close of the Middle Ages, primarily as a result of European contact with Arabic and oriental culture—prophetic, as it were, of the future when the whole character of European civilization was to be transformed from the contact of Europe with extra-European lands. In mathematics the Arabs transmitted to Europe the so-called Arabic numerals, which were probably of Indian origin and facilitated simplified arithmetical calculations which were impossible with Roman numerals, the algebraic notation which allowed Galileo, Descartes, Napier, Newton and Leibnitz to carry on the development of mathematics to the calculus, an achievement denied to Archimedes because of the lack of an adequate notation, and the Greek contributions to geometry which had been largely lost during the early medieval period in western Europe. In optics Alhazen and others carried on the contributions

[12] Thorndike, *op. cit.*, pp. 616–687.

[13] *Ibid.* We have not here assumed to discuss the validity of the so-called Roger Bacon manuscript which, if genuine, would seem to indicate that Bacon anticipated Hooke in the use of the microscope by some four centuries. For a summary of the situation see *Harper's Magazine*, July, 1921, pp. 185–197. For Bacon's contributions to optics see C. Singer, "Studies in the History and Methods of Science," Vol. II, pp. 121 ff.

of Euclid and other Greek workers in this field, executing preliminary achievements in the way of manufacturing lenses and mirrors, which were of indispensable significance for the further development of the sciences like biology and astronomy, which depend upon the utilization of the microscope and telescope, to say nothing of the services rendered to the mitigation of failing eyesight, and the inspection, adornment and possible beautification of the human anatomy. Clocks were developed as far as the principle of the balance clock, possibly from Arabic models, thus initiating the progress which led to the ultimate perfection of the stop-watch and the appearance of reliable dynamic mechanics.[14]

While the Arabic and Christian alchemists did not provide the philosopher's stone and achieve transmutation of metals and personal rejuvenation, they did discover or utilize certain useful chemicals, such as antimony, saltpeter, arsenic, zinc, bismuth, manganese, ether and metallic salts, which furnished the basis for the work of the early chemists from Paracelsus onward, who endeavored to divorce chemistry from the supernaturalism and mysticism of alchemy and to secure its concentration upon practical technical problems. The ultimate outcome of the work of the alchemists thus justified Francis Bacon's notable figure when he said that "alchemy may be compared to the man who told his sons that he had left them gold buried somewhere in his vineyard; while they by digging found no gold, but by turning up the mould about the roots of the vines procured a plentiful vintage. So the search and endeavors to make gold have brought many useful inventions to light."[15] The Arabs also brought to Europe the knowledge of paper-making. The Chinese had probably been the first to manufacture paper, making it out of the pulp of the mulberry tree. The Arabs had substituted cotton-fibre and introduced paper of this type into Spain. The Europeans adapted flax and rags to its manufacture, and paper-making had become relatively common in Europe by the close of the thirteenth century. In this manner the invention of printing by means of movable type in the middle of the fifteenth century was given practical significance through the prior provision of abundant material on which to operate this new technique.[16] Last, but by no means least important, there should be mentioned the mariner's compass, which is first mentioned by an English monk, Alexander Neckham, at the close of the twelfth century. It was the compass, more than any improvement in ship-building, which en-

[14] Sedgwick and Tyler, "A Short History of Science," pp. 156–190.

[15] E. Thorpe, "A History of Chemistry," Vol. I, pp. 28–56.

[16] H. A. Maddox, "Paper: Its History, Sources and Manufacture."

abled Columbus to execute successfully a trans-Atlantic voyage and paved the way for European expansion overseas in the sixteenth and seventeenth centuries—a movement fraught with more consequences for the history of western civilization than any prior development in the history of western Europe.[17]

IV. The Renaissance in Intellectual History

A generation ago it was fashionable to assign great importance to the Renaissance in the development of modern civilization. In the works of the esthete Symonds and the poet Burkhardt one finds the general thesis that the Middle Ages were a period of general and relatively uniform stagnation, the paralyzing shell or envelope of which was burst by the potent forces arising from the new appreciation of classical literature and the remarkable developments of chromatic and plastic art during the two centuries following 1450. The most diverse results of a progressive nature have been assigned to such factors and causes, not even excepting the rise of modern science, the mastery of oceanic navigation, and the rise of the national state system. The results of a generation of historical scholarship have been such as totally to dissipate this illusion. In the first place, we have learned much more about the real nature of the Middle Ages. It has been shown that they can not be dealt with as a unified period, there being an enormous gulf between the culture of Merovingian France and the Italy of Dante. It was not an era of uniform cultural stagnation; particularly from the twelfth century onward there was a steady, if gradual, intellectual and scientific improvement, and the Renaissance, as such, did little to stimulate these tendencies in any unique manner. In the second place, it has been shown that it is manifestly inaccurate and misleading to throw together all the multifarious and diverse cultural developments of the period from 1450 to 1700 and assign them to the Renaissance. If this term is to have any specific meaning whatever it must be held to refer to Humanism and the developments in art. The latter may be left out of this discussion.[18]

As to Humanism it can scarcely be proved that the laudable increase of interest in, and approval of, the literatures of Greece and Rome produced any remarkable intellectual revolution, least of all any marked impulse to renewed scientific curiosity. The only direct contribution which Humanism made to the new science lay

[17] Thorndike, *op. cit.*, Vol. II, pp. 199, 387–388.

[18] J. T. Shotwell, "Middle ages" in Eleventh Edition of the *Encyclopedia Britannica;* J. H. Robinson, "The New History," pp. 154–160; "Petrarch," second edition, Introduction; H. O. Taylor, "Thought and Expression in the Sixteenth Century," Preface and Chap. I; K. Brandi, "Das Werden des Renaissance."

in the recovery and reading of some of the writings of the Greek scientists who had far more modern and acceptable ideas on scientific matters than those of most medieval figures, but instances of this sort were very few and relatively unimportant. The most encyclopedic of all the Greek scientists, Aristotle, had been well known to the Schoolmen in good translations from the Greek from the close of the thirteenth century onward.[19] The Humanists were much more attracted by rhetorical and mystical pagan works than by the scientific treatises of antiquity. Cicero and Neo-Platonic writers loomed far wider on the horizon than Aristarchus, Archimedes or Hipparchus. As Professor Robinson has judiciously said:

> The so-called Renaissance offers nothing comparable to the achievements of the twelfth and thirteenth centuries. It is true that in the fourteenth and fifteenth centuries the Italian towns developed an interesting civilization and a marvelous art different from that which went before. These have perhaps blinded us to the relatively slight contributions of the period to general change. To one who is intent upon establishing the continuity of history the men of letters, the philosophers, and even the artists of the Renaissance, exhibit an extraordinary intellectual conservatism. They transcended relatively few of the ancient superstitions, contributed but little to the knowledge of the world, and readily yielded to the fascination of Neo-Platonic mysticism, as is illustrated by Ficino, Pico and Reuchlin.
>
> As has been said elsewhere, it was quite possible to read the classics without becoming forthwith Hellenic in one's attitude of mind. It may be safely said that as one's acquaintance with the Middle Ages, as well as his appreciation of our own time, increases, the Renaissance seems to grow more and more shadowy as a distinctive period; and yet many writers use the term as if the Renaissance were a bright spirit, hovering over Europe, touching this writer and that painter or architect, and passing by others who were in consequence left in medieval darkness. . . .
>
> It is a grave mistake to assume that this renewed interest in the Greek and Roman authors betokened a revival of Hellenism, as has commonly been supposed. The libraries described by Vespasiano, a Florentine bookseller of the fifteenth century, indicate the least possible discrimination on the part of his patrons. Ficino, the translator of Plato, was an enthusiastic Neo-Platonist, and to Pico della Mirandola the Jewish Caballa seemed to promise infinite enlightenment. In short, *Plato was as incapable in the fifteenth century of producing an intellectual revolution as Aristotle had been in the thirteenth.* With the exception of Valla, whose critical powers were perhaps slightly stimulated by acquaintance with the classics, it must be confessed that there was little in the so-called "new learning" to generate anything approaching an era of criticism. It is difficult, to be sure, to imagine a Macchiavelli or an Erasmus in the thirteenth century, but it is likewise difficult to determine the numerous and subtle changes which made them possible at the opening of the sixteenth; and it is reckless to assume that the Humanists were chiefly responsible for these changes.[20]

[19] E. Emerton, "Beginnings of Modern Europe," Chap. ix–x; H. O. Taylor, "Thought and Expression in the Sixteenth Century," Book I.

[20] J. H. Robinson, "The New History," pp. 116–117, 157–158.

The most significant and potent impulse given by Humanism to intellectual and scientific advance was an indirect one, consisting in a revival of interest in the things of this world. The intellectual classes among the pagans, by contrast with the Christians, had been singularly little interested in the supernatural world or the destiny of the soul. They were primarily concerned about the most happy, adequate and efficient type of life here on earth. Philosophy was designed to teach how to live successfully rather than how to die with assurance of ultimate safety in the arms of Jesus. This dominant secular interest had been lost for approximately a millennium on account of the Christian absorption in the problems and technique of the salvation of immortal souls, and Augustine himself had warned against becoming too much engrossed in earthly interests lest assurance of successful entry into the New Jerusalem be jeopardized. As men like Petrarch and his followers and successors came to read more of pagan literature and to approve it heartily, they were inevitably infected with the virus of the secular orientation of the Greek and Roman past, and there arose the amusing situation of actually pious Humanists enthusiastically recommending what was frankly branded by Augustine as an undoubted and integral portion of the City of the Devil.[21] Erasmus admitted that the appellations St. Socrates and St. Cicero were neither inaccurate nor inappropriate and sacrilegious. He thus openly expressed his preference for pagan writers when compared with even the most illustrious Schoolmen:[22]

> Whosoever is pious and conduces to good manners ought not to be called profane. The first place must indeed be given to the authority of the Scriptures; but, nevertheless, I sometimes find things said or written by the ancients, nay, even by the heathens, nay, by the poets themselves, so chastely, so holily, and so divinely, that I can not persuade myself but that, when they wrote them, they were divinely inspired, and perhaps the spirit of Christ diffuses itself farther than we imagine; and that there are more saints than we have in our catalogue. To confess freely among friends, I can't read Cicero on "Old Age," on "Friendship," his "Offices," or his "Tusculan Questions" without kissing the book, without veneration towards that divine soul. And, on the contrary, when I read some of our modern authors, treating of politics, economics and ethics, good God! how cold they are in comparison with these! Nay, how do they seem to be insensible of what they write themselves. So that I had rather lose Scotus and twenty more such as he (fancy twenty subtle doctors!) than one Cicero or Plutarch. Not that I am wholly against them either; but because, by the reading of the one, I find myself become better, whereas I rise from the other, I know not how coldly affected to virtue, but most violently inclined to cavil and contention.

That the generation of an interest in the secular world was an

[21] E. M. Hulme, "Renaissance and Reformation," Chaps. i–xi; P. Monroe, "Textbook in the History of Education," Chap. vi.

[22] K. Pearson, "The Ethic of Free Thought," pp. 165–166.

impulse in the direction of scientific curiosity, as compared with the supernaturalism and eschatology of Patristic and Scholastic Christianity, can not be denied, yet it was but a feeble and indirect urge, which was probably far more than offset by the anti-scientific tendencies of the Humanistic movement in education. This is still extant and well reflected by the notion that a college student majoring in physics, chemistry or biology can make no claim to any true education and culture as compared with one who has shown proficiency in wrestling with the ablative absolute, hortatory subjunctive or future periphrastic, and should, accordingly, have his barbarism properly stigmatized by the degree of bachelor of science. It was the mystical and esthetic, rather than the scientific and rationalistic, attitude which was promoted by the spirit of Humanism, and at its very best it could do no more than to produce the learning of a Scaliger or Casaubon or the broad-minded tolerance of a Montaigne. Humanism could no more produce the modern world than the Greek and Roman culture upon which it was based. And, finally, what slight indirect impulse Humanism may have given to secular studies and science was obstructed or frustrated by the revival of supernaturalism and bigotry in the period of the Reformation and Counter-Reformation. By the time scholarship had recovered from this blow, the explorers and scientists had created a new world of fact and ideas quite foreign to Erasmus, Luther, Baronius and Loyola alike.[23]

The invention of printing, which came as a result of the labors of Coster and Gutenberg in the period of Humanism, was a very important contribution to the ultimate development of a technique which is so much a thing of cooperative effort and effective communication as modern science, but here again the service was indirect and incidental rather than causal. There was no immediate flood of radical or scientific books. The majority of the books printed during the first century or so after Gutenberg were not scientific and critical works but pious religious and theological books, usually a reproduction of those which had appeared in the centuries before the invention of printing as a result of the patient and persistent efforts of medieval copyists in the monastic *scriptorium*. It was not until the sixteenth and seventeenth centuries that books reflecting the beginnings of the new thought and science were printed in any considerable number. Neither did printing make it easier to produce progressive books. The European governments made unlicensed printing a serious offense, in some states

[23] Preserved Smith, "The Age of the Reformation," Chap. i; "Erasmus," Chaps. ix, xii, xv; E. Feuter, "L'Histoire de l'Historiographie Moderne," Livre I.

a capital crime, and established a thorough censorship of the licensed presses. The precarious nature of the printing profession in regard to the issuance of novel scientific or philosophical works is well illustrated by Osiander's famous preface to Copernicus' work, in which Osiander, to protect his press, implied that probably Copernicus was only joking. To-day this sort of censorship functions chiefly as regards text-books.[24]

V. The Place of the Reformation in European Intellectual History

Even less than the Renaissance did the Reformation and Counter-Reformation directly promote a scientific and critical point of view or encourage interest in mundane and secular affairs. It has been assumed by many that the Renaissance produced the Reformation, but it seems that this is true only in the sense of a somewhat ironical remark once made by Professor Robinson to the effect that the mythical Renaissance may have caused the mythical Reformation. Between Humanism and Protestantism there was little real intellectual affinity or genetic relationship, however much there may have been of personal identity and interrelationship between Humanists and Reformers. If any of the Protestant reformers derived inspiration from the Humanists, it was from the piety and Christianity of the scholars and not from their Humanism. If Luther was impelled to ecclesiastical and doctrinal reform by his study of Erasmus' writings, it was due to the ideas of Erasmus the Christian and not to those of Erasmus the Humanist. The exuberance of Erasmus over the writings and doctrines of Saint Cicero could never have been the starting point for the theological views and intellectual attitudes of a Luther, a Calvin, a Knox or a Jonathan Edwards. Cicero's beautiful little motto, which might appropriately serve as the starting-point for tolerant thinkers in all ages, "We who search for hypotheses are prepared both to refute without prejudice and to be contradicted without resentment," could hardly have been the fountain-spring from whence Calvin derived his canons of hospitality, as exemplified in his treatment of Servetus after their little friendly tilt over the nature of the Trinity.[25]

The important point is that, strictly speaking, Humanism, on the one hand, and Lutheranism and Calvinism, on the other, were

[24] Smith, "Age of the Reformation," pp. 8–10, 418–424; J. H. Robinson, "Mind in the Making," pp. 10–11; "The Humanizing of Knowledge," pp. 64–69.

[25] J. B. Bury, "History of the Freedom of Thought," Chap. iv; K. Pearson, "Ethic of Free Thought," Chaps. viii–ix.

fundamentally divergent and opposed. Humanism was a moderate and rather unconscious revolt against the supernaturalism and other-worldliness of Patristic and Scholastic Christianity; the Protestant revolt brought with it an all-pervading revival of even the grosser forms of supernaturalism, diabolism, miracle-mongering, witchcraft and a host of other phases of this general cultural complex. Even some of the Protestant protests against certain symptoms of alleged worldliness in the Catholic Church of the early fifteenth century may be regarded as of dubious validity, when viewed from a strictly historical, scientific and secular standpoint. In short, Humanism and the Reformation were highly divergent in general cultural orientation and intellectual outlook, and we may agree with Erasmus that if Luther hatched the egg which he (Erasmus) had laid, it was quite a different bird from what Erasmus had intended. Professor Preserved Smith's criticism of Karl Pearson's lack of superior and definitive erudition on such matters as the Renaissance and Reformation is undoubtedly justifiable, but it seems that Pearson stumbled on materials which have led him to formulate exactly the correct interpretation of the divergent viewpoints of Erasmus and Luther in the famous chapters of his "Ethic of Free Thought."[26]

Some Protestants have taken great pride in the elimination of many alleged idolatrous practices of the Catholics which was effected by the Reformation, but their exultation rests upon dubious foundations. By doing so they enormously weakened the emotional power of the church and took from it one of its most potent forces and appeals in visual and oracular imagery. The rich emotion-bearing ritual and liturgy of the Catholic church is far better adapted to attracting and holding the mass of faithful believers than the metaphysical dogmatism of Calvin or the savage vocal emotionalism of our evangelical Protestant cults. The intellectual classes, who were once attracted by the Calvinistic metaphysic, have now generally discarded all types of orthodoxy, and it may well be that the heroic evangelistic gymnastics of Billy Sunday and his kind are required to fill up the depleted ranks of Protestantism chiefly because of the fatal strategy of the leaders of early Protestantism in giving up most of the impressive Catholic ceremonial of worship. And no candid critical observer is likely to regard the miracle of the mass and its attendant ritual, or images of Jesus, the Virgin and the Saints, as more or less pagan and idolatrous than baptism, or various phases of Protestant theology which have a definite Greek basis. Probably no one has more sagaciously

[26] Preserved Smith, "Erasmus," pp. 433–434; Pearson, *op. cit.*; C. Beard, "The Reformation in its Relation to Modern Thought and Culture."

summarized the necessary and desirable qualifications upon exuberance over the progressive intellectual tone of Protestantism than Professor Robinson.[27]

The defection of the Protestants from the Roman Catholic Church is not connected with any decisive intellectual revision. Such ardent emphasis has been constantly placed upon the differences between Protestantism and Catholicism by representatives of both parties that the close intellectual resemblance of the two systems, indeed their identity in nine parts out of ten, has tended to escape us. The early Protestants, of course, accepted, as did the Catholics, the whole patristic outlook on the world; their historical perspective was similar, their notions of the origin of man, of the Bible, wifh its types, prophecies and miracles, of heaven and hell, of demons and angels, are all identical. To the early Protestants, as to Catholics, he who would be saved must accept the doctrine of the triune God and must be ever on his guard against the whisperings of reason and the innovations suggested by scientific advance. Luther and Melanchton denounced Copernicus in the name of the Bible. Melanchton re-edited, with enthusiastic approval, Ptolemy's astrology. Luther made repeated and bitter attacks upon reason; in whose eyes he freely confessed the presuppositions of Christianity to be absurd. Calvin gloried in man's initial and inherent moral impotency; and the doctrine of predestination seemed calculated to paralyze all human effort.

The Protestants did not know any more about nature than their Catholic enemies; they were just as completely victimized by the demonology of witchcraft. The Protestant revolt was not begotten of added scientific knowledge, nor did it owe its success to any considerable confidence in criticism. As Gibbon pointed out, the loss of one conspicuous mystery, that of transubstantiation—"was amply compensated by the stupendous doctrines of original sin, redemption, faith, grace and predestination" which the Protestants strained from the epistles of St. Paul. Early Protestantism is, from an intellectual standpoint, essentially a phase of medieval religious history.

Without attempting in any way to pass judgment upon the theological merits or validity of the positions taken by Protestant reformers, it may be pointed out that the majority of historians have now accepted the view that the great significance of the Reformation lay in the political and economic movements associated with it, rather than in the purely religious and theological problems and issues involved. In line with the suggestions made long ago by Sleidanus and Harrington, contemporary writers like James Harvey Robinson and Max Weber have shown that the most vital phases of the Reformation period were the rise of the independent sovereign states and the ideals and practices of the modern *bourgeois* business man, which God was supposed to have initiated and to have given his unqualified approval.[28]

[27] J. H. Robinson, "The New History," pp. 117–118.

[28] J. H. Robinson, "The study of the Lutheran revolt," in *American Historical Review*, January, 1903; J. H. Robinson, article "Reformation," in Eleventh Edition of the *Encyclopedia Britannica*; M. Weber, "Die Protestantische Ethik und der Geist des Kapitalismus," in *Archiv für Sozialwissenschaft und Sozialpolitik*, 1905; Smith, "Age of the Reformation," Chap. xiv; R. H. Tawney, "Sixteenth century religious thought," in *Journal of Political Economy*, 1923.

Intellectually speaking, the Reformation was most decidedly backward-looking. Theologically it assumed to go back to the Apostolic age. Luther denounced the universities, designated reason as the devil's most seductive harlot whose neck faith could easily wring, revelled in devil and miracle-mongering, and was the first important European to condemn the Copernican theory, his grounds being that the theory was preposterous in the light of the fact that "in the day when Jehovah delivered up the Amorites before the children of Israel Joshua said in the sight of Israel, 'Sun, stand thou still upon Gibeon,' and the sun stood still and the moon stayed until the nation avenged themselves of their enemies." The Calvinistic anthropology, with its morbid basis in the concept of human treason before God, and his predestinarian theology, were alike intellectually depressing and abhorrent. And no person could be less sympathetic with science and critical philosophy than a fanatic like Knox. Then, the Protestant emphasis on the infallible nature of the Bible was in some ways more dangerous and obstructive to progressive thought and scientific advance than the Catholic dogma of an infallible Church which might periodically alter its tenets. The Protestants might be more readily forgiven for their Bibliolatry if they had evidenced a major concern with the teachings of Christ, but instead they revived an interest in, and primary emphasis on, the Old Testament, with all its savagery and anachronisms, which served well as a basis for the Sabbatarian excesses of the Puritans.[29]

About the only contribution to intellectual progress which can be assigned to Protestantism is the indirect aid which it gave to the growing difficulty in ecclesiastical repression of the freedom of thought and expression. This was foreseen and deplored by Bossuet. As he clearly pointed out, once the unity of Christendom had been broken by the Protestants, there was no reason why the process should not go on indefinitely and lead to the multiplication of innumerable Protestant sects, thus making it impossible to enforce any unity of doctrine. It was in this matter of rendering ecclesiastical interference with thought less easy and effective, through promoting the disunity of Christian belief and organization, that Protestantism aided, if at all, in advancing intellectual progress. In a minor sense Calvinism, with its emphasis on the God-given calling of money-making, may be said to have promoted the fostering of those phases of applied science that have been closely related to modern industry and the practical applications of the "theory of business enterprise."[30]

[29] Pearson, *op. cit.*, Chap. ix; Smith, "Age of the Reformation," Chaps. xii–xiii; A. C. McGiffert, "Protestant Thought before Kant," Chaps. i–v.

[30] Fueter, *op. cit.*, pp. 329–331; E. Gibbon, "Decline and Fall of the Roman Empire," Chap. liv; R. H. Tawney, *loc. cit.*

The reaction of the Protestant revolt on Catholicism was intellectually more disastrous than its effect upon the followers of Luther and Calvin. The cultural degradation which came with the Catholic defence-reaction in the Counter-Reformation can best be gauged and measured by the contrast between a typical pre-Reformation Catholic like Erasmus and the most characteristic figure in Counter-Reformation Catholicism, Ignatius Loyola. While no movement founded by an Erasmus could have produced a Voltaire, as the most cursory comparison of the "Adages" with the "Philosophical Dictionary" will readily demonstrate, neither would it have naturally led to the creation of the Jesuit Order. The church had been growing more tolerant and more appreciative of secular learning, when it was put on the defensive by the Protestant assaults and felt it necessary to recover, revivify and defend vigorously monstrous dogmas which had been partially allowed to lapse, and to defend as grotesque and repellant a supernaturalism as that propounded by any Protestant fanatic.[31] Protestantism and Counter-Reformation Catholicism collaborated in producing and enacting the most degrading and depressing drama in the history of western civilization—the witchcraft mania and delusion of the sixteenth and seventeenth centuries. It is a pleasant task to turn from this abysmal culmination of the revival of supernaturalism in early modern times to the parallel and synchronous achievements of the scientists who were discovering a new heaven and a new earth.[32]

VI. The Discovery of the New Heavens and the New Earth

If neither the Renaissance nor the Reformation can well be regarded as forward-looking or progressive movements which notably aided in producing the modern scientific and critical outlook, the adequate and potent causes for the origins of modern times can be located in the rise of modern science and the expansion of Europe overseas, with the many and varied results which came from this process.[33]

It is futile to attempt to discover or assign any specific cause for the *rise* of modern science; in fact, it is probably inaccurate to use that term, for modern science was not a sudden development but a gradual growth from the time of Gerbert onward. The new knowledge from the east, the new intellectual life promoted by

[31] Smith, "Age of the Reformation," Chap. viii.

[32] Smith, *op. cit.*, pp. 651–661; W. E. H. Lecky, "The Rise and Influence of Rationalism in Europe," Chap. i; C. Singer, "Studies in the History and Methods of Science," I, pp. 189–224; J. M. Robertson, "A Short History of Free Thought."

[33] J. R. Seeley, "The Expansion of England," Book I, Lecture v.

the rise of the towns and universities, the overseas explorations and discoveries, and the cumulative ferment and knowledge from these sources, all combined to bring about the remarkable outburst of scientific activity and achievement of the sixteenth and seventeenth centuries. In general, the whole movement was, consciously or unconsciously, a revolt against the deductive method and spiritual objective of Scholasticism—a conviction that the new body of saving knowledge was to be found through an observation of nature, and that in this procedure the Scholastic technique was impotent because, as Bacon himself expressed it, "Nature is more subtle than any argument."[34]

Perhaps one major reason why the first remarkable results of early modern science were so impressive was the fact that it was directed towards a majestic and imposing problem and objective—an investigation of the nature and movement of the heavenly bodies. Few would claim that Kepler and Galileo were greater scientists than Huygens and Leeuwenhoek, but the field of their labors was one designed to give their results a more compelling interest and widespread wonder and admiration. It should be remembered, of course, that while the Schoolmen had accepted it and Dante had immortalized it in his *Commedia,* the cosmology of the early sixteenth century was not a Christian but a pagan product. The Scriptural cosmology was one which represented the earth as a minute slab of earth and water supported on the void and lighted with heavenly bodies of varied candle-power which studded the canopy of the heavens at no great distance from the earth—a system similar to that to-day taught in the schools of Zion City where Voliva gives proof of greater astronomic literalness and piety than was exhibited by the learned Aquinas and the poet Dante. One is moved to an ironical smile when he contemplates the fear of Copernicus, the persecution of Galileo, and the martyrdom of Bruno at the hands of Christians for uprooting a wholly pagan cosmology and theory of celestial mechanics.[35]

Copernicus did little to modify the Hellenic celestial mechanics which had been accepted by Christendom beyond exchanging the positions of the sun and the earth in the vast and complicated arrangement of fixed crystalline spheres, thus transforming it from a geocentric to a heliocentric system. But Giordano Bruno perceived clearly the implications of the shift from a geocentric to a heliocentric universe and set them forth with impressive clarity and comprehensiveness. Among his hypotheses damaging to the

34 Smith, *op. cit.,* pp. 609–624; C. Seignobos, "History of Medieval and Modern Civilization," Chap. xvii.

35 Singer, *op. cit.,* Vol. I, p. 31.

cosmology of the Christian Epic were such things as the infinite size of the universe, the lack of finite limitations on, or a fixed center for, the universe, the fallacy of the doctrine of the rigid crystalline spheres, with the substitute conception of the free motion of the heavenly bodies in space, the relativity of space, time and motion, the ever-changing positions and relations of the heavenly bodies, the similarity or identity of the constituent materials in the heavenly and earthly bodies, and, above all, the particularly disconcerting concept of the plurality of worlds. When to these challenging innovations in cosmic philosophy was added a tendency towards the popularization of such doctrines it is not hard to understand why the Catholic church of the post Counter-Reformation type interfered and arranged the speedy translation of Bruno. Most of his views were at the time pure guess-work, but all have been confirmed by the subsequent developments of celestial mechanics and astrophysics and chemistry.[36]

The succession of figures who laid the definitive basis for the celestial mechanics which held the field largely unchallenged until the era of Einstein consists of Tycho Brahe, Kepler, Galileo and Newton. Tycho Brahe, quite in the spirit of old Hipparchus, carried on a careful study of the heavens and gathered concrete data of great value for later theorists. The first of these was his assistant, Johannes Kepler, who showed that the planets moved in elliptical paths rather than circular, that they travelled most rapidly when nearest the sun, and that there was a fixed relation between the cubes of their distance from the sun and the squares of their times of revolution. Galileo founded dynamic mechanics by his famous law of falling bodies, which he arrived at as a result of a classic example of experimental science, an achievement so significant that Bergson is said to have remarked that modern science came down from Heaven along Galileo's incline-plane. Isaac Newton, a half century after Bacon's age, combined Kepler's third law with Galileo's law of falling-bodies in his famous law of inverse squares or universal gravitation, which was not only the crowning achievement of seventeenth century science, but the inspiration for much of the liberal philosophy and theology of the eighteenth century. The old heavens, not merely of Genesis and the astrologers, but of Aristotle and Ptolemy, had been wiped away and a new cosmos of infinite expanse and complexity had been substituted, and it is very curious that pious theologians have not understood that this new astronomy was far more of a challenge to the fundamental tenets of the Christian Epic than the Darwinian

[36] G. Forbes, "A History of Astronomy," pp. 30–39; D. Stimson, "The Gradual Acceptance of the Copernican Theory of the Universe"; W. Boulting, "Giordano Bruno."

theory of evolution.[37] The remarkable development of science in the seventeenth century, which has been so well described by Professor Shipley, came for the most part after Bacon had been gathered to his fathers, but the stage was set for it by the achievements and impulse of Kepler and Galileo, of which it was a natural outgrowth.[38]

Even more significant in creating the modern age were the varied cultural results of the expansion of European civilization overseas and the reaction of this process upon European life and institutions. Cultural historians and anthropologists have long recognized that the contact of cultures is far and away the most potent force in breaking down cultural stagnation and provincialism—in other words, the most dynamic factor in history. This all-important progressive force had earlier manifested itself during the period of the Crusades with certain results noted above, and had not failed to maintain itself as an important factor in European history from that time onward, but the era of its greatest potency followed the successful voyages of Columbus and Vasco da Gama. The elucidation of this set of historic influences, which has been the work of historians from Raynal to W. R. Shepherd, has been probably the most important contribution which historians have made to the subject of the setting of the work of both Francis Bacon and early modern scientists.[39]

First and foremost among the forces and impulses coming from European expansion should be put the general disintegration of the medieval and feudal system, and the substitution of a generally novel social and political system, in short, the actual transformation of the whole face of European civilization through the stimulation of the spirit of adventure, scientific curiosity, new knowledge, the rise of world commerce and large scale oversea colonization, modern capitalism and capitalistic institutions, the increase of urban life, the rise of the middle class, and the gradual extinction of the feudal system to be supplanted by the national state, first on a dynastic and absolutistic basis, and later on a representative and parliamentary foundation. In cooperation with

37 Sedgwick and Tyler, *op. cit.*, Chap. x; H. Höffding, "History of Modern Philosophy," Vol. I, pp. 103–183; H. O. Taylor, "Thought and Expression in the Sixteenth Century," Vol. II, Chap. xxiii; A. D. White, "History of the Warfare of Science and Theology," Vol. I, Chaps. iii–iv.

38 Sedgwick and Tyler, *op. cit.*, Chaps. xi–xiii; A. E. Shipley, "The Revival of Science in the Seventeenth Century."

39 W. R. Shepherd, "The expansion of Europe," in *Political Science Quarterly*, 1919; and Unpublished Lectures on the Expansion of Europe; W. C. Abbott, "The Expansion of Europe"; E. Feuter, *op. cit.*, pp. 361–380, 434–449, 475–483.

the Protestant *Ethik* it altered the attitude of religion towards economic practices by eliminating the social point of view and stressing the sanction and approval of God for the ultra-individualism of modern capitalism, with its emphasis upon pecuniary profit as the most pleasing of all achievements in the sight of God. It was this great series of interrelated transformations that laid the basis for the Industrial Revolution and the exploitation of modern sciences and technology which has produced contemporary civilization.[40]

In its specific contributions to science the expansion of Europe was by no means unimportant or negligible. Most directly influenced was the science of navigation, with its accessory sciences of mathematics, engineering and optics. The explorations and discoveries not only enormously increased the concrete geographic information of every type, but stimulated scientific cartography upon the basis of determinable latitude and longitude. Astronomy was enriched by the discovery and observation of constellations in the southern hemisphere, and by the scrutiny of hitherto known heavenly bodies from new positions on the earth's surface. Additions were made to chemical knowledge by the discovery in oversea areas of rocks and minerals of new and significant types. Botany, the materia medica and zoology were remarkably aided and advanced by the great variety and number of newly discovered forms of plant and animal life. And a strong if not adequate stimulus was given to the movement which ultimately founded the science of man or anthropology through the contact with a large number of new racial and sub-racial types in widely different degrees of cultural development. With the equally marked influence of the results of the expansion of Europe on art, literature and currents of thought this is not the place to deal. It is worth pointing out, however, that it did much to stimulate that appreciation of diversity and relativity which loomed large in Baconian thought as compared with that of Aquinas. It is evident that this movement, as a whole, produced a new earth in two important senses; in the first place, by discovering the western and southern hemispheres, and, in the second place, by changing the cultural complexion of the world that had been known before 1500. It is doubly significant for the scientist, in that it not only stimulated many phases of modern science, but also did much to create that contemporary intellectual, economic and social world in which present-day science can function.[41]

[40] A. F. Pollard, "Factors in Modern History"; W. Cunningham, "Western Civilization," Vol. II; J. E. Gillespie, "The Influence of Oversea Expansion on England"; C. J. H. Hayes, "Political and Social History of Modern Europe," Vol. I; Tawney, *loc. cit.*; W. J. Ashley, "Economic History of England," Vol. II, pp. 456 ff.

[41] E. R. Turner, "Europe, 1450–1789," Chaps. v–xxiv; Gillespie, *op. cit.*, Chaps. viii–ix; T. Veblen, "The Place of Science in Modern Civilization."

Such, then, was the world into which Bacon was born. With the possible exception of the fifty years from 1875 to 1925, there has not been a more interesting or crucial period than the half century from 1575 to 1625, in which Bacon passed the productive period of his life. It was the era which carried natural science from Copernicus and Vesalius to Galileo, Napier and Harvey, and prepared the way for the magnificent achievements in the next half century associated with such names as Newton, Huygens, Swammerdam, Boyle, Leibnitz and their contemporaries. In historic conditions at large the first permanent settlements were being made in the New World and the stage was set for those interactions between the Old and New World that have been a leading factor in both cultural and political history from that day to this, and are in a humble but fitting way represented by this occasion.[42]

As to the problem of Bacon's place in the civilization of his day and the degree to which he showed himself aware or appreciative of the scientific methods and achievements of his age, these are matters which may be left to the more competent and better informed authorities who will follow me on this program. On the one side are the extreme partisans of Bacon who look upon him as the real founder of the inductive and experimental method, whose writings have been the point of departure for all the subsequent workers in the scientific field. On the other side are John William Draper and others who take his position, namely, that Bacon was a cheap charlatan who was neither able to make any contributions to science himself nor to appreciate the work of contemporary scientists. Obviously, the truth falls somewhere between these two extremes. It is well known that Bacon failed to appreciate the work of men like Copernicus and Galileo, he certainly was not great as a technical scientist, and it is doubtful if he ever had much direct concrete influence upon specific scientists in their laboratory or observational work, beyond the fact that his "New Atlantis" was the model on which the Royal Society was constructed. At the same time, he rendered a great service in putting his matchless rhetoric at the service of the inductive and experimental method, and in giving the newer method of approaching the problems of knowledge some general currency among educated classes. To fix in the minds of the intellectual class of his age the fundamental thesis that "Nature is more subtle than any argument," thereby branding for all time as inadequate the Aristotelian technique which had been elaborated and relied upon by the Schoolmen, was a real contribution. As deadly as his attack upon the dialectical technique of the medievals was his assault upon the subservience of the faithful to

[42] F. S. Marvin, "The Living Past," Chap. viii.

authority and tradition. By showing that, all other things being equal, every generation is manifestly wiser than its predecessor, as far as the cultural heritage is concerned, and by representing anachronistic authority as the most likely and prevalent form of Satanic manifestation, he showed faith and credulity to be even less trustworthy than "reason."[43]

So, it seems to me, that we shall go far astray if we seek in Bacon the Einstein, the Karl Pearson, the J. Arthur Thomson, the Bergson or the John Dewey of the first quarter of the seventeenth century, but I believe that we shall be on the right track if we attempt to see in him the James Harvey Robinson of his age. In his effort to create a respect for critical and scientific ways of thinking and to improve the lot of mankind thereby, he was the most potent worker of his age in the cause of creating an interest in the process of the making of our minds and in the humanizing of knowledge. Mr. Taylor has briefly but clearly summarized Bacon's contribution, when viewed from this angle:[44]

> He was a great influence in his time and after, spurring men to independent thinking. He urged them to study nature and make experiments and hold fast to facts; and likewise to practical purposes. With many others he protested against subservience to authority; in language and imagery not to be forgotten he showed the Idola, the fetishes, the aberrances and pitfalls of human reason; he set forth a method of induction which, whether practicable or not, might tend to guard men against rashly drawn conclusions. And above all, with intellectual enthusiasm, he urged men on, proclaiming the sure and far-reaching powers of the mind for the attainment of serviceable truth.

[43] See the judicious summary in Taylor, *op. cit.*, Vol. II, pp. 355–372.

[44] Taylor, *op. cit.*, Vol. II, p. 372. For Bacon's interesting plea for intellectual history, see Robinson, "The New History," p. 101.

ENDOWMENT, MATURITY AND TRAINING AS FACTORS IN INTELLIGENCE SCORES[1]

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As my hearers well know, the past few years have witnessed an unusual interest not only on the part of psychologists and educators but also on the part of sociologists, publicists and many well-informed laymen as well, in the theory lying behind the construction of intelligence tests and more particularly in the interpretation of the results secured by their use. An excellent illustration of this unusual interest is afforded by the controversy precipitated by Mr. Lippmann's series of articles in the *New Republic* and by Dr. Bagley's address at Chicago before the Society of College Teachers of Education—which has led to pronouncements by Dr. Terman, Dr. Yerkes, Dr. Thorndike, and to which the present speaker alluded at length in his address as retiring vice-president of Section Q at the Boston meeting of this association. The fact that those immediately concerned in the construction and use of intelligence tests are fully alive to the problems raised and the difficulties presented in this field is also well attested by the tone and spirit of the series of articles by Thorndike, Colvin, Pintner, Miller, Trabue, Rugg and others in the Twenty-First Yearbook of the National Society for the Study of Education on "The general principles of intelligence tests and their administrative use," issued in 1922. The ready sale of this volume and of similar treatises on intelligence tests and their applications shows the interest of schoolmen in the topic, and the critical and controversial reviews that have appeared of such interpretations of intelligence testing as Goddard's "Human Efficiency and Levels of Intelligence" and Brigham's "A Study of American Intelligence" show the concern that is felt by many thoughtful writers in the implications of the movement in question.

I take it that the papers read to-day have been asked for because of the situation just described. It is felt that it would be well for psychologists to review here certain of the more technical issues that have risen and to indicate, if possible, the nature of their ultimate solution.

Before stating what seem to me to be the issues of special im-

[1] Read before Section I, American Association for the Advancement of Science, Cincinnati, December, 1923.

portance in connection with the topic assigned, I would like to recite a sort of *Credo* which, I think, will contain a series of beliefs to which practically all of us are willing to subscribe. Dr. Freeman has done the same sort of thing in his "Referendum of psychologists" in the December, 1923, issue of the *Century Magazine*. Perhaps I may be pardoned for paraphrasing some of Dr. Freeman's statements in view of the fact that I was one of those whose views were solicited for his referendum.

(1) I believe that, while definitions of general intelligence given by the devisers of tests vary in detail (see the symposium on "Intelligence and its measurement" in the *Journal of Educational Psychology*, March and April, 1921), they may be substantially brought into agreement with the phrase: "ability to learn," "to profit by experience"—not merely to learn in the sense of memorizing, then, but ability to assimilate, to coordinate and subordinate items of fact, to appraise them and utilize them in further thinking, especially in prevision, in anticipating the outcomes of situations, both real and imaginary.

(2) I believe that there would be substantial agreement, furthermore, that the forms of intelligence tests now commonly in use put special stress upon that phase of learning that deals with verbal content, with the more abstract, as distinguished from the concrete aspects, of learning; in short, with that aspect of learning that is of primary importance for success in the school.

(3) I believe that intelligence tests as now constructed and operated form the best single device that we possess for measuring this aspect of intelligence. They have gained the highly important pragmatic sanction that they work. Properly administered and interpreted, they provide a prediction of school success which exceeds in validity such other predictive criteria as school marks, teachers' estimates, previous school history, and the like.

(4) I believe that one of the main reasons why this high degree of practical serviceability has been attained is the fact that the makers of the tests have proceeded methodically; that they have invariably sought to standardize their instructions, their material and their statistical methods of handling the results.

(5) I believe that no intelligence tester can lay claim, and so far as I know, none has laid claim, to measure *all* the significant elements of the individual personality. Every maker of tests will agree that conative and emotional aspects of mental activity which are of the greatest significance for daily life remain practically untouched by the stock intelligence tests, and will agree that special forms of mental tests which will yield information concerning these other aspects of personality are greatly to be desired.

(6) More than this, I believe that no intelligence tester has laid claim even to measure all the significant aspects of intellectual endowment in the individual personality. For example, numerous special aptitudes, like the aptitude for music, for mechanical pursuits, for drawing, for dramatics, for appreciating and meeting social situations of all sorts, are untouched. We do not even secure by the general intelligence test any adequate and thorough-going measure of any single aspect of that intelligence: we do not, for instance, secure a complete inventory of the subject's reproductive or recognitory memory, of his range of apprehension in all the possible modalities, of his discriminative sensitivity, of his capacity for continuous constructive thinking on a complex topic, of his sanity of judgment when issues are complex or clouded by bias and partisanship.

(7) I believe that every maker of tests of general intelligence readily admits that he measures that capacity indirectly. We seek to determine the individual's intrinsic capacity by the efficiency he displays in the intellectual performances we demand of him; in short, we estimate what he could do by what he does do.

(8) I believe we all agree that what the examinee does do in a given test is obviously a net resultant of several factors, among which may be mentioned his attitude toward the examiner and toward the examination, his zeal, his general physical condition, his native intellectual capacity, his stage of maturity, and the extent and character of his training (including the sum of the environmental forces that have contributed to the making of his general mental equipment, and more especially those aspects of his training equipment that the particular tasks of the particular examination bring into play).

(9) I believe that the extent to which test results are vitiated by the first few of these factors—the examinee's attitude toward the examination, his zeal and his general physical condition—is usually much exaggerated in the popular mind. Experience shows that a skilful examiner can almost always secure proper cooperation and the output of a reasonable amount of zealous effort. Experience also shows that general physical condition plays comparatively little part in determining such wide differences of score as are actually obtained in most comparative tests.

These nine statements of my *Credo,* then, represent what I believe are nine points of agreement concerning the theory of intelligence testing. I pass now to more debatable issues, to those concerned with the extent to which the remaining factors contribute to the typical intelligence test score. I shall leave out of consideration the factor race and for the moment the factor sex and shall make use especially of three terms to describe the other factors under discussion—namely, endowment, maturity and training.

Definitions of the Factors Endowment, Maturity and Training

By *endowment* I shall mean the innate, constitutional quantum of general intellectual capacity. This I conceive to be substantially given at birth by inheritance. It is the distinguishing element of intellectual efficiency, the factor that makes the individual different fundamentally from other individuals in intellectual grasp. Whether it is biologically a unit character or the resultant of numerous unit characters is not pertinent to this discussion. The extremes of this quantum are typified in the idiot and in the highly gifted (or perhaps in the genius).

By *maturity* I shall mean that stage of development, that degree of unfolding, of this constitutional intellectual endowment which has been attained by virtue of the ripening of the individual's general mental efficiency brought about by the mere passage of time. If we could conceive of a given child at two years of age who then proceeded to live for one year without the slightest contact with the environment, the alteration in his mentality that would have taken place by the end of that year would be the effect of the factor maturity operating alone.

By *training* I shall mean the sum total of the effects upon the intellectual operations of the individual of any and all sorts of external or environmental influences—the casual stimuli of daily life, the formal processes of education in the school, the effects of illnesses—all that we commonly think of as the effects of the environment.

With these explanations of terms before us, the immediate problem may be stated thus: Is it possible by means of our intelligence tests to arrive at a reasonably satisfactory appraisal of endowment, uncomplicated by maturity or by training? Or, in other words: Can we know the relative part played by endowment, by maturity and by training in the scores of our tests?

The Factor Maturity

Certain things can surely be agreed upon at once with respect to maturity. For instance:

(1) We never actually arrive at an indication of an endowment which is not that endowment as presented at a given maturity and as influenced by a given amount of training.

(2) There is some evidence that in the case of individual children chronological age might well be replaced by physiological age as an index of maturity. Investigators like Dr. B. T. Baldwin, who have studied this matter more fully, recommend, as I understand it, that this substitution be made. It may be that in time we shall

have criteria of physiological age that are so reliable and so easily determined that this age will become commonly accepted as the index of maturity.

(3) One obvious illustration of divergence of physiological from chronological age (and therefore of the difficulty of defining maturity) lies in the sex differences characteristic of the early adolescent period. It is known to every one that girls as a group mature physiologically earlier than do boys as a group. Studies that I am now making of thousands of scores of the National Intelligence tests show that the average scores of girls exceed the average scores of boys at the age of 11 years by almost one mental year. Incomplete data on other years appear to indicate that this sex difference is less at earlier ages but augments at about 11 and 12 years—which is, after all, what we should expect from results with other forms of mental and physical tests. As is also well known, the scores of postpubescents in the Army Alpha tests run higher for males than for females. Even if, as some contend, the content of the Army Alpha favors males, it is doubtful whether this favoring can be so great in amount as to bring the score, when properly discounted for this alleged fault of construction, to the point where females excel males so greatly as they do in the initial period of adolescence.

Consequently, concealed in these *sex* differences, we really have, as I said, a good demonstration of the operation of physiological *maturity* as a factor in intelligence scores. We are not justified, I mean, in assuming that the National Intelligence score of a 12-year-old postpubescent girl which is 10 points higher than that of a 12-year-old prepubescent boy indicates a superior endowment for the girl. The two children might well have the same endowment as well as the same chronological age.

(4) Disregarding these irrelevancies introduced into chronological age by the complication of physiological age when the two are not in step-by-step correspondence, the present methods of eliminating the factor maturity by such devices as mental age, intelligence quotients, age norms and age percentiles seem to me to have demonstrated their effectiveness by the results of repeated examinations of the same individuals; in other words, it seems to me that the constancy of the I.Q. is substantially all that could be asked for practical purposes.

(5) A problem of serious theoretical and considerable practical import appears when we seek to answer the question: At what chronological age does maturity cease to operate as a factor; in other words, what is the normal adult mental age limit? Many

pages of controversial matter have appeared on this issue. I have no intent to summarize them here. I would merely give my opinion that much of the difficulty into which psychologists have been plunged by the attempt to reconcile Binet scores and Army Alpha scores and tests of children and tests of adults lies in the fundamental difficulty of comparing directly the scores of school children and of adults on tests devised primarily for children alone or primarily for adults alone. Dr. Freeman (*Jour. of Educ. Research*, December, 1922) very properly says that we can not assume "that the average man, who has been out of school for from five to ten years, who has done very little reading and has been provided very meager intellectual stimulus, will do as well on a test standardized on school children as he would have done while he was in school." In the terminology I have been using, then, the elimination or the measuring of the influence of maturity as a factor is, in the case of those who have left school for some time, complicated by our third factor, that of training. What we need to settle this particular matter conclusively are retests after the lapse of several years with no further formal education on adults who have previously been tested while in school. I am hoping to institute an investigation of this sort shortly.

Three observations may be made at this point, however, that shed, I think, a little light on this problem of the relation of test scores to maturity.

First: In the Merrill-Palmer Nursery School operated at Detroit, where the psychological work is directed by Dr. Helen Woolley, the children, most of whom enter the school between the ages of two and five, are given a Binet test on or before entrance and are retested one or more times thereafter. A study of the I.Q.'s shows that, with a few exceptions, there is a marked rise in these I.Q.'s after six months or more attendance in the school. The question at once arises: Is the alteration here due to shifting of endowment or of training (or, perhaps, even in an acceleration of the normal rate of maturity)? Personally, I hesitate to believe that Mrs. Woolley and her colleagues have discovered a new method of heightening the I.Q. It seems to me entirely to be expected that the acquaintance with numbers, days of the month, colors and all the other materials and facts that are bound to be presented, even in the simple and informal training of a nursery school, has produced a temporary artificial augmentation of apparent mental age. Further retests, after these children have settled down in the earlier grades of the primary school, will, I venture to predict, confirm this interpretation. Here, then, is an instance in the lower age

levels of the complication by special training of the normal effect of maturity upon intelligence scores.[2]

A second observation: In comparing the scores made by college students and senior high school students in educational tests and psychological tests, I have been struck with the divergence between these two types of scores. Thus, at the University of Michigan, scores made by juniors and seniors in the Iowa High School Content Examination (which deals exclusively with factual information in literature, rhetoric, mathematics, the sciences, history and civics) show a marked advance over the scores obtained by high school seniors or university freshmen in the same test. On the other hand, the scores made by the same juniors and seniors in the Brown University psychological examination differ only slightly from the scores of university freshmen in that test. From this I draw the inference that the Brown examination is comparatively successful in measuring endowment, uncomplicated by training, and further that the pure maturity effect of the nearly four years between approximately the ages of 17 and 21 is relatively slight (this partly because some portion of the slight improvement found between the freshman and the senior year must be discounted as due to college training and also to the operation of elimination).

A third observation: I made a special attempt recently to secure satisfactory data on the National Intelligence tests for the ages beyond the elementary-school period. In one Michigan city it was possible to test every 14-year-old and every 15-year-old child. The average scores for 14 and 15 years were 139 and 142, respectively, *i.e.*, the performances in these two ages were practically indistinguishable. The annual increments of scores for the same test, beginning at the step from 8 to 9 years, are 15, 15, 17, 16, 15, 9, 3. This seems to confirm very definitely the idea that on the average at about 14½ years maturity ceases to be a factor at least so far as these tests are concerned.

[2] Another explanation is conceivable. Possibly, under some circumstances (as, for instance, when systematic training is given in the plastic early years of childhood) special training may for a time accelerate the normal rate of maturity. That is, maturity, as we have defined it, brings about a progressive ripening of intellectual efficiency, regardless of training, but this ripening might conceivably be hastened by certain types of training given at certain times. This hastening of maturity would be an indirect effect added to the direct augmentation of efficiency produced by the training. For example, the presentation to a three-year-old child of numerous stimuli, skilfully assembled in the form of educative plays and games, might stimulate in him certain activities of associating, comparing and deliberating that would not have emerged in the natural course of his internal development until a year or so later.

The Factor Training

In discussing the factor maturity we have already found occasion for mentioning the participation of the factor training. A few words more about this factor.

The disentangling of *training* from endowment is in some respects more difficult than the disentangling of maturity. Our usual procedure in interpreting intelligence tests is, of course, to assume that, other conditions being the same (especially extent of opportunity or amount of exposure to schooling) differences in the test scores of persons of the same maturity are fairly direct indications of differences of endowment. As I said before, we judge what the individual can do by what he does do. I believe that most investigators will agree to this interpretation, though they may not agree as to the exact precision with which performance is thus indicative of endowment.

The real divergence of opinion doubtless lies in the question: How often may we regard these "other conditions" as "being the same"? In such cases as the children in the nursery school who had two or three years of more or less systematic arrangement of their environment during what is ordinarily the pre-school age, it is perfectly evident that other conditions are not the same, that we can not then argue safely from intelligence score to native capacity.

In many other cases in which the actual educational environment has been diverse, we are, I believe, often at a loss to determine how much to discount for the superior environment, for the particular reason that endowment is itself a factor that conditions environment. It has been fairly well demonstrated, I mean, that heredity to some extent makes its own environment. Karl Pearson, for example, from his studies of heredity, is very emphatic in his assertion that differences of stock condition differences of environment. Families of superior intellectual endowment are never content with an inferior intellectual environment. The fact that such families struggle for, and usually gain, an intellectual environment satisfying their felt needs certainly influences their children through the factor of earlier, more extensive and qualitatively better training. Some considerable part, therefore, of the better scores made by these children which are *immediately* attributable to their superior training must, after all, be *ultimately* ascribed to their better endowment.

To take a concrete illustration of these complexities: a certain boy, now 9 years old and just completing the fourth grade, has an I.Q. in the neighborhood of 140. He is at least one grade pedagogically accelerated when his school grade is compared with his age. On looking over his school history, however, we find that he

did not enter school until over 7 years of age, so that, when allowance is made for this late entrance, he really is two years or more pedagogically accelerated. From this point of view his opportunities for training have been less than those of a standard child, so that his school performance is all the more remarkable. Going back a little, we discover that he learned to read spontaneously at about the age of three and one half years. At this time he began of his own accord to pick out simple words on the typewriter. When he entered school at 7, he chanced to try the Buckingham-Ayres spelling scale and scored "eighth grade" in spelling ability. Now, how is this performance to be interpreted? Strictly speaking, for a boy with substantially no public school training to attain an eighth-grade performance means, when proper allowance is made for the lack of maturity and training, that his intrinsic ability in spelling ought to be regarded as nearer, let us say, that of the twelfth grade. In other words, the attainment of an eighth-grade score while in the second grade means really better than eighth-grade ability. But, it will be objected, this boy had been playing with a typewriter for several years, hence his early training and unusual home influences have really accounted for his performance. My answer to this objection is that the fact that the boy had these opportunities set before him is one of the products of the superior intellectual endowment of his parents (presumptively transmitted to the boy), and the further fact that he profited by the opportunities set before him is one of the products of his own superior intellectual endowment, so that, on both counts, the attainment, despite the fact that it sprang from unusual environmental opportunities, merely reflects and measures superior endowment.

Further examples of this reciprocal interaction of endowment and training lie at hand in various quarters. Thus, the fact that college students, in overwhelming numbers (about 90 per cent.) score "A" or "B" grades (very superior or superior) in the Army Alpha test is, in my judgment, a demonstration of the selective influence of the college and not a demonstration of the training effect of higher education. Mention need be made only of the serious difficulty encountered by "C plus" and "C" grade students in their attempts to assimilate a college training.

The same conclusion—that intelligence tests, other things being approximately equal, are conditioned mainly by hereditary endowment—can be illustrated by reference to the correlations obtained between test scores and school performance. I am indebted to Dean S. A. Courtis, of the Detroit Teachers College, for the following illustration. When the scores in a composite intelligence test (National Intelligence test and Detroit Army Alpha) are compared with the school marks (composite of reading, writing, arithmetic,

spelling and English) the correlation for a group of a given school grade of all ages, both sexes, and mixed previous training is about 0.40. If the group is rearranged to cancel the factor maturity (by taking only 11-year-old pupils, though of different grades) and to cancel the factor sex (by taking only boys), the correlation rises to 0.60. When the group is further rearranged also to cancel approximately the difference in the value of the school marks from grade to grade, the correlation rises to 0.70. In short, endowment is seen to be the most important single factor, and it is not unreasonable to suppose that if other factors, like emotional reaction, zeal, effort, motor ability, and the like, could be held constant, and if the reliability of the school marks could be brought to perfection, the correlation between score and the factor endowment would also approximate perfection.

It might be added that a particular reason why endowment is, in practice, the most important factor to determine is that it is the one factor that we can not *control* in our educative process. Maturity we can not directly control, either, but we invariably take account of it in our educational plans. Training we must seek to control to the best of our ability, given the endowment and picking the appropriate stage of maturity so far as is feasible.

Endowment, Maturity and Training Tests

If this approximation toward a perfect correlation between intelligence score and the outside criterion of intelligence were found to be only partial, we might do well to examine our tests themselves in order to discover whether we had failed to construct them properly. I mean that we may firmly believe that theoretically endowment is a primary element in intellectual success but yet admit that our present tests may not, after all, measure this endowment adequately. Such a situation would exist, for instance, if in the composite of tasks which makes up our present intelligence examinations there are to be found certain tasks, certain individual tests, which are really little affected by endowment, though possibly considerably affected by maturity or by training.

In the second edition of his *Vorlesungen* Meumann published a proposed new system of tests wherein ten tests were assigned to each age-level and wherein these ten tests were so classified that they served as endowment, maturity and training tests, respectively. The actual plan proposed by Meumann was not practicable, nor did he give us any satisfactory reasons for assigning the various tests to the three classifications, yet the proposal raises the interesting question as to whether or not such a three-fold division is theoretically possible or desirable.

In the first place, it is questionable whether tests that are out-and-out training tests should have any place in an intelligence examination at all. It is quite true that certain tests that are obviously measures of degree of competence in certain school subjects have found a prominent place in intelligence tests; nearly all intelligence tests, for instance, designed for application in the school grades above the third have included arithmetical computation or arithmetical problems. Nevertheless, the intent has not been to measure knowledge of arithmetic or skill in the fundamental processes as such (for these purposes we employ specific arithmetical tests), but to measure intrinsic capacity, and these "schoolish" tests can be defended only on the ground that, with pupils who have all been exposed to more or less similar training in these fields, the performance shown is substantially conditioned by endowment. Quite the same thing can be said of the "range of information" tests which are also a common feature in our present intelligence tests. Personally, I believe that the effort should be made to avoid so far as possible tasks that are so directly influenced by home environment and school instruction.

In the second place, the question arises: Is it possible, or desirable to differentiate between tests of the two other main conditions of intellectual performance, between endowment tests and maturity tests? Presumably, if an analysis of scores showed that certain tests varied sharply with chronological age, but varied relatively little within a given age for children of known differences in endowment, such tests could be termed "maturity tests." (Meumann states that the immediate memory test is an instance in point.) Similarly, if the analysis of scores showed that other tests varied decidedly for children of known differences in endowment, but varied relatively little with chronological age, these tests could be termed "endowment tests." On the basis of tests conducted with feeble-minded children of a limited range of ages, Chotzen ("Die intelligenz-Prüfung Methode von Binet-Simon bei schwachsinnigen Kindern." *Zeits. f. Angew. Psych.* 6: 1912, 411–494) declares that this differentiation appears clearly; the maturity tests, or "age-tests," as he calls them, are those concerned with frequently performed activities and the experiences of everyday life, whereas the endowment tests are those that present something new, demand something novel and necessitate keenly concentrated attention. Claparède ("Tests de développement et tests d'aptitudes." *Arch. de Psych.*, 14: 1914, 101–107), who has also been interested in this problem, has proposed what seems like a severe measure, that tests shall be deemed maturity tests only when the difference between the average performance of two successive age-levels shall be at least four times the probable error of the distribution of the scores

of a single age-level, or only when the percentage of right answers (in the case of "all-or-none" tests) increases from 10 to 80 from one age-level to the next.

When to these difficulties of a statistical sort are added the further complications that some tests appear to correlate more definitely with maturity in one respect but with endowment in another respect, and that the great majority of tests after all correlate definitely with both maturity and endowment, we are led to question whether the differentiation between these two types of tests is really feasible in practice. Further comparative studies might, I judge, be carried on to good purpose in this direction. Generally speaking, it would seem desirable to exclude from our intelligence examination any test that exhibited marked correlation with chronological age coupled with low correlation with endowment.

As to the great majority of tests, which, as just mentioned, exhibit definite correlation with both maturity and endowment, are we not warranted in saying that it is precisely this type of test that we seek if we are to work on the basis of mental ages at all? Was it not the essential feature of Binet's plan that the quantity of endowment possessed by a child should be determined by comparison with the degree of endowment normal to children at a given stage of maturity? Naturally, we are committed by this analysis to the further assumption that endowments which differ at the start will exhibit similar (or perhaps even greater) differences at various subsequent stages of maturity; in other words, we are committed to the doctrine of the substantial constancy of the I.Q. Certainly we can not hope at present to devise any satisfactory series of tests that shall measure endowment regardless of the effects of maturity. We work on the basis that performance superior to the average performance for the stage of maturity reached means superior original endowment.

It had been my original plan to conclude this paper with a statement of the general arguments for the fundamental significance of hereditary endowment in intellectual performance and a discussion of the very important problem of the extent to which training at different stages of maturity is conditioned by different degrees of endowment. I would have liked, for instance, to debate Bagley's hypothesis that while "vertical growth," as he calls it, is limited, the possibilities of "horizontal growth" are essentially limitless. In a way, these are problems of general educational psychology and only subsidiary issues of the theory of intelligence testing. You will be glad to pardon their omission at this time and for reasons of time economy to pardon also the absence of any summary of this paper.

THE INTERPRETATION OF INTELLIGENCE TESTS[1]

By J. McKEEN CATTELL

We are conscripted to talk this morning about the interpretation of our intelligence tests, with special reference to the problem of the extent to which the performance of the individual depends on his heredity and on his environment. The scientific method of interpreting psychological tests is to continue research with them. Definitions and discussions are relatively futile for the advancement of science; but they may serve a social function. Certainly if we want to play a complicated game of logic and logomachy, heredity, environment and intelligence are excellent counters.

Apart from theology there is perhaps no subject so inaccessible to scientific research, so open to endless discussion, as is human heredity.

> As flies to wanton boys, are we to the gods,—
> They kill us for their sport.

Professor Morgan and his thirteen disciples can mate, etherize and count their flies by the tens of thousands. It requires the omnipotence of the gods and the time of their slowly grinding mills to make in men modifications equally significant; and they breed and kill us for purposes other than the collection of scientific records. Only in the fable can Fata Morgana transform a human being. Morganatic marriages for experimental results are not favored by existing law and sentiment.

When I became editor of *The American Naturalist,* it was with the intention of making it a journal devoted to research on heredity and organic evolution; my own interest was in human heredity and eugenics. Within these twenty years a science of genetics has been created, but there have been submitted to the journal scarcely any papers of consequence on human heredity; not many have been published anywhere. When the International Congress of Eugenics met in New York two years ago, there were many officers and members, but scarcely half a dozen of them professionally engaged in eugenical research.

Some three hundred years before there was a Davenport in Iowa or in Cold Spring Harbor, Hakluyt in his "Voyages" wrote:

[1] Part of the Symposium of the Section of Psychology of the American Association for the Advancement of Science at the Cincinnati meeting, December 31, 1923.

"I reason that as some sicknesses are hereditarious and come from father to the sonne, so this inclination or desire of this discovery I inherited of my father." This is the natural extension of the concept from its original application to the inheritance of rank and property and is the current usage; thus the "Century Dictionary": "The influence of parent upon offspring; transmission of qualities or characteristics, mental or physical, from parents to offspring;" and the "Oxford Dictionary": "The property of organic beings, in virtue of which offspring inherit the nature and characteristics of parents and ancestors generally."

We might expect better things in Baldwin's "Dictionary of Philosophy and Psychology" where the definitions are signed by experts, but we find heredity defined conventionally as "The transmission from parent to offspring of certain distinguishing characteristics of structure or function." This definition is scarcely an example of the transmission of characteristics from parents to offspring, for, according to the signatures, the mountains which were in labor to bring forth the little monster were Professor J. Mark Baldwin, Professor E. B. Poulton, Professor William James, Principal C. Lloyd Morgan and Professor G. F. Stout. It is inept to personify heredity, to make a fundamental distinction between structure and function, to speak of characteristics as things apart from the organism handed down like property, or to make the parent (why not at least the parents?) solely responsible. In general, however, the usage is the current one, and if we define heredity as "The resemblances among individuals due to their common origin or germ plasm," we have the problem to which our genetic investigations are directed.

But in the subject proposed for this discussion, "Heredity *vs.* environment in the interpretation of our intelligence tests," heredity has a different meaning, namely, the congenital equipment or the original organization of the individual. This usage has biological sanction; for example, Professor J. Arthur Thomson in his book on "Heredity" writes: "Heredity, function, and environment —famille, *travail,* lieu—are the three sides of the biological prism, by which, scientifically, we seek to analyze the light of life." This is a curious sentence, as light is analyzed by two, not by three, sides of a prism, and experience is not coordinate with congenital equipment and environment, but dependent on them. Galton, whose intellectual vision was always sharp, uses what he calls the "jingle" of "nature and nurture," to mark the distinctions with which we are here concerned. He says: "Nature, or the sum of inborn qualities . . . includes also those individual variations that are due to causes other than heredity, and which act before birth." And

Brooks: "We must recognize the universality of the law of heredity, but we must not overlook the equally well-established fact that each organism is the resultant of this law and another, the law of variation."

As we have no satisfactory word for the constitution of the fertilized ovum—the zygote—it is a temptation to use heredity, but it causes confusion. Thus, on the one hand, the zygotes of two brothers might by hypothesis be assumed to be identical, but the influence of environment to be so dominant that under different conditions there would be no resemblance between the two adults. Or, on the other hand, the zygotes of the same parents might conceivably vary normally about the racial mean, but two similar zygotes, whatever their origin, might under diverse environments produce similar adults. With which of these extreme hypotheses would heredity be strong or weak? We apparently should find or invent words to designate the individual when it is a zygote and when it is born, and the extent to which at these stages the growing or adult organism is determined.

Environment is also a complicated concept. It is a term that I have never liked; for some obscure reason it reminds me of "that blessed word Mesopotamia." Alcohol is no longer part of our lawful environment, but it may on occasion be found in the brain. Is it then part of the organism or of the environment? To which do vitamins, hormones and internal secretions belong? The behavior of a blind man is dependent on this condition. Blindness may be due to organic heredity or to chemical changes induced in the germ plasm of the parents; it may be caused by infection in the uterus or by subsequent disease to which there is congenital disposition; it may result from actions due to imbecility or from driving a car recklessly; it may be due to lightning from heaven. We lack everywhere sharp lines between the organism and the environment. The reactions of an individual are determined by stimuli acting on a nervous system formed largely by preceding experiences, and in an environment which is largely a social heritage.

Even if we know exactly what we mean by our words, it is not possible to answer categorically the question whether the intelligence displayed in our tests is due to heredity, or to environment, or to a certain proportion of each. Mr. Lippmann would not care to answer the question: Did you misrepresent the opinions of psychologists in your *New Republic* articles through ignorance or through malice? To ask whether the performance of an individual is due to "heredity" or to "environment" is like asking whether the color of a flower is due to the molecular structure of the petals, to the light that they diffuse, or to the perceiving individual. To

use the old simile of Aristotle: "A hand apart from the body is no longer a hand." The organism and the rest of the world with which it comes in contact are one and inseparable. When the blind lead the blind and both fall into a pit, it is not easy to say whether the result is due to the individual or to the environment. And so it is with the actions of Kaiser Wilhelm or Czar Nicholas. A boy may do about as well in his college work by natural ability tempered by athletics and fraternities, or by lesser ability more continuously applied. The same causes produce the same effects, but the same effects can be produced by varying causes. "Some men are born great, some achieve greatness and some have greatness thrust upon them."

Darwin and Lincoln were born on the same day. Darwin came from a highly endowed family with all the advantages of wealth and privilege. He chanced to go on the voyage of the *Beagle* and lived when and where evolution by natural selection—witness Wallace—was in the air. Lincoln had no hereditary advantage or favorable surroundings; but he too had high natural ability and finally the opportunity of circumstance. If the two infants had been exchanged there would have been no Darwin and no Lincoln. Was the performance of each due to natural endowment or to opportunity, or to any quantitatively determinable proportion of the two? Is the amount of the extension of a spiral spring due to the structure of the spring or to the weight attached? As nearly as the matter can be put in a sentence we may say that what a man can do is determined by his native equipment, what he does do by the circumstances of his life. We can not gather figs of thistles; neither figs nor thistles will grow where there is no water.

If there are difficulties in reaching a common understanding in discussing heredity, environment and their interrelations, the situation is not other with regard to intelligence. The psychologist is likely to consider intelligence as the quality enabling an individual to learn readily or to meet new situations successfully, in so far as this depends on his congenital equipment. This is what we mean when we say that a dog is more intelligent than a horse, or to quote Hakluyt again: "In my judgment there is not a beast so intellective as are these eliphants, nor of more understanding in al the world; for he wil do al things that his keper saith, so that he lacketh nothing but humaine speech."

In common usage, however, intelligence means information, especially the limited sort possessed by intellectuals or the intelligentsia. Thus the *Dial* heads its December advertisements: "It is now the fashion to be intelligent," and continues: "Until recent years it was still considered fairly bad form to be intelligent; to be

well-read was either a snobbish superfluity or a social misdemeanor." Intelligence is not only used for information and appreciation in literature, but we are told of intelligence departments of the army, where spies and clerks collect dubious information, and in America we call places "intelligence offices" on the Ciceronian principle of *lucus ab non lucendo.*

Our intelligence tests may not be misnamed, for they measure the combined natural and acquired ability of the individual to deal promptly and correctly with relations that are largely verbal and mathematical. This kind of intelligence is needed for success in school and college work, so here the tests have a considerable predictive value. Such abilities develop with age; the child reaches a stage at which he can talk, read, calculate or acquire certain kinds of information, as happens with walking, swimming or playing tennis. Genetic tests of the Binet type thus have great value in determining mental age, but this is a concept that should be applied with caution to adults. It is also the case that the qualities measured by the tests are required in our present civilization, especially in the professions. But the ambiguity of the word intelligence may lead to false interpretations. It may mean a hypothetical native quality that leads to success in most situations, or it may mean acquired skill in dealing with words and numbers. We may measure the latter and assume that we have determined the former.

It seems that I was responsible for the first psychological measurements of "individual differences" and for the invention of this term as well as of the term "mental tests." My experiments on the rate of reading and its dependence on the method of presentation, published in 1885, were of the intelligence test type. It may, perhaps, be now revealed without indiscretion that John Dewey, then my fellow student, stood highest in the group tested. I found that a word could be read as easily as a single letter; that a subject might require about one half second to read a single word, about one fourth second each to read disconnected words in series and about one eighth second each to read words in sentences. In reading different languages aloud as rapidly as possible without attention to the meaning, my own time per word in thousandths of a second was: English 138, French 167, German 250, Italian 325, Latin 434 and Greek 484. The relations were found to measure the individual's ability in the language. It took about twice as long to name a color or an object as the word designating it for those habitually engaged in reading, but not for others. The times of the different observers were distributed approximately in accord with the normal probability curve, within a range of about 1 : 2, which I have found to hold for many psychological measurements of indi-

vidual differences, such as reaction-time, observation, memory, association and judgment.

In 1887 and 1889 there were described in the *Philosophische Studien* and in *Mind* over 12,000 experiments on the association of ideas on the lines of our present intelligence tests. The subjects included the students of a German gymnasium, a London school, a Dublin school and Bryn Mawr College. The experiments were published some ten years earlier than the work of Dr. J. M. Rice, which is often quoted as the first quantitative study of school children, and some twenty years before the Binet tests, which are usually regarded as the first genetic or age intelligence tests. In four forms of the London girls' school the average ages of the students were 12.7, 14.8, 16.3 and 17.8 years; the average times of their associations in seconds were 9.33, 6.09, 5.16 and 4.13. There was also a regular increase with age in the percentage of abstract associations.

The following paragraph scarcely seems antiquated:

> The 363 students of the London school were divided, according to their class-rank, into four parts. The average time of association for each quarter is given in Table IV. This shows an increased rate of association as the class-rank of the students is higher, but the difference is not great. Indeed, it is possible that such experiments measure the alertness of the student's mind more accurately than does the class-rank, which depends largely on diligence and other factors not telling in such experiments. The table does not show a difference for the several quarters in the relative rate of the concrete and abstract associations; consequently higher class-rank does not seem to be accompanied with greater ease in abstract thought, attention to objective details being equally useful. (*Mind*, XIV, p. 235, 1889.)

I then employed the word alertness and still prefer it to intelligence. Scott uses the term "mental alertness tests," but the adjective is unnecessary. The designation "psychological tests" seems to be preferable to "mental tests" or "intelligence tests." Ability is a better word than intelligence, for we can speak of different kinds of abilities, and the word refers to measurable performance rather than to mysterious mental powers. I have always held that psychology has to do with the conduct of an individual rather than with his consciousness. We are concerned with what a person does, rather than with what he thinks he thinks, feels he feels or imagines he imagines. In psychological experiments, as I once put it, "It is usually no more necessary for the subject to be a psychologist than it is for the vivisected frog to be a physiologist."

Perhaps some light is thrown on the contemporary interpretation of intelligence tests by the following, written nearly forty years ago:

> The differences of time in the several cases are explained by the character and pursuits of the subjects, and in turn throw light back upon these. For

example, B is a teacher of mathematics, C has busied himself more with literature; C knows quite as well as B that $5 + 7 = 12$, yet he needs 1/10 seconds longer to call it to mind; B knows quite as well as C that Dante was a poet, but needs 1/10 seconds longer to think of it. . . . In giving the language in which an author wrote, as average of the three trials, . . . in the case of Luther B took 244, in the case of Goethe 102σ less time than C; in the case of Shakespeare C took 186σ less time than B. It should be borne in mind that B is a German, C an American. . . . Such experiments lay bare the mental life in a way that is stratling and not always gratifying. (*Mind*, XII, p. 71, 1887.)

In the "Physical and Mental Measurements of the Students of Columbia University,"—which in accord with the present system of psychological nomenclature and to make permanent an otherwise untenable association might be called the "Cattell-Columbia tests" —published in 1896, the effort was made to measure or record a large number of specific individual traits. In the course of an hour some twenty-six measurements were made in the laboratory and some forty-four observations were recorded. Later the student sent in answers to some fifty questions in regard to his origin, condition, habits and interests. We had his records in class work and in the gymnasium; information concerning non-scholastic college activities was available. What the men have done in the subsequent twenty-five years and the measurements of the children of some of them at present in college could now be correlated with the original determinations. The measurements were made on women at Barnard as well as on men at Columbia—about a thousand in all—and were genetic tests; for the same individuals were tested at the beginning of the Freshman and the end of the Senior year.

It is to be hoped that these references to early work are not symptoms of arteriosclerosis. It seems to me that in recent years exact measurements of psychological traits and reactions have been relatively neglected for the more general and complicated intelligence and information tests, whose immediate usefulness is greater. Perhaps the best way to interpret intelligence tests is to study the more elementary forms of behavior on which they in part depend. Individuals were found in these Columbia tests to differ in strength, fatigability, vision, hearing, touch, accuracy and rate of movement and of perception, observation, attention, imagery, memory, association, etc., but there was little or no correlation among the measurements or of these with the class standing of the student in different subjects. This lack of correlation may, however, be in itself of interest. It parallels the lack of transfer of training found by Professors Thorndike and Woodworth in the Columbia laboratory.

It may be that quickness and accuracy are not directly correlated. They may be inversely correlated; but both are useful traits. If there is no correlation, 25 per cent. of individuals would be above

the median in both quickness and accuracy and would have a distinct advantage. If "intelligence" and "character" are not correlated, one per cent. of all individuals would stand in the upper tenth in both characteristics and these would tend to be those who are successful in their behavior. Psychologists do not hold that there is a comprehensive and unanalyzable native general intelligence on which the success in life of the individual depends; but such opinions are attributed to them, and it may be that individual psychologists have not always expressed their meaning with sufficient care and caution.

In my study of eminent men, begun in the eighties, I applied psychological classifications to group them as men of thought, men of action and men of feeling. I have noted the analogy of thought, action and feeling to the wider categories of space or extensity, time or protensity, and energy or intensity, and also the circumstance that performances are not divided among the three kinds of activities, but possess them in varying degrees, as a body may be round, moving and hot at the same time. These distinctions were used in grading character and in arranging individuals in the order of merit for different traits. Some people are most happy and successful in abstractions, all the way from solving newspaper puzzles to framing systems of philosophy, others in social relations or artistic activities, others in doing practical and objective things. These abilities are combined in varying degrees and relations and are then exhibited in different kinds of performances. Human nature is endlessly complicated and the kind of analysis that can be made with pen and ink is rather futile. We are told that thought is antithetical to feeling and action, but accomplishment in some directions rests on a combination of the three, witness, for example, British premiers such as Gladstone and Lloyd George. Even so we have not settled with the question of clearness of thought, sincerity of feeling, correctness of action. Wisdom, sympathy, righteousness are still further beyond our present reach.

In all this complex the intelligence tests only attempt to determine a small range, primarily of the intellectual processes. If children have had much the same home and school life the tests measure native differences in what an individual can and can not do. The morons at the bottom will not be found in the upper school grades, but may be conscripted to serve in an army. A girl in the lower deciles may be a good housemaid but a poor typist; somewhat higher, she may be a competent typist, but a stupid stenographer. Freeman says in his excellent study in the December *Century Magazine*, that "leadership in the professions, in business and in larger political life" is confined to the upper five or ten per

cent. I should prefer to guess that nine tenths of the leaders would be placed by our tests in this group. Among the five or ten million Americans thus designated the correlations are uncertain and vary with the kind of performance. To be a Phi Beta Kappa man or an Alpha A + man is an introduction to "Who's Who" and a salary of $5,000. The men who build cities, railways and industries are not selected by intelligence tests.

When it is found that Italian children in our schools do not do so well in certain tests as native American children, this may be due simply to lack of familiarity with the language or to ease in understanding the instructions. The children in the Montessori schools seem to be particularly precocious in tests of the Binet type. In any case the Italians may have forms of expression unattainable by the usual Anglo-Saxon. When Irish children do not do as well as some others, it may be due only to different interests in the home, but these interests may reflect real racial differences. The tests may predict that the Irish children will not do as well as American children in bookkeeping and stenography; but they do not directly measure the probable success of the two groups in keeping saloons, running Tammany Hall, writing poetic drama, or starting rows. There is in fact fair agreement among psychologists on the scope and meaning of intelligence tests. The difficulties are largely in the minds of journalists and educators, as Professor Whipple pointed out in the admirable review of the subject in his address given a year ago as chairman of the section of education of this association.

The proper interpretation of intelligence tests consists in learning what an individual will do in a given situation, what are the conditions leading him to act as he does, how well we can predict this. Our current tests foretell as accurately as an entrance examination or a high-school record what a boy will do in college. That is practically important for it gives a more nearly equal chance to those who have had varying opportunities. Boys from the private preparatory schools pass the college entrance examinations more readily than those from the public high schools, but they do not do so well in their studies afterwards. What is hopeful about the tests is that they predict what a boy can do even more accurately than what he will do. In this direction future research is full of promise. No work seems to me more important for society than Terman's on the selection of talented children. A great forward step has been taken when psychology is applied to useful purposes and the way is made straight for a profession that may become as serviceable as medicine or engineering.

THE ORIGIN, NATURE AND INFLUENCE OF RELATIVITY[1]

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III. The Old and New Theories of Gravitation

It is a commonplace of experience that when material objects are left free, they fall to the earth. If suspended from above they stretch downward, and if supported from below they flatten in the same direction. It is customary to think of such effects as due to gravitational force. This force acts with nearly the same intensity everywhere on the earth's surface. Very careful experiments indicate that it is proportional to the mass or quantity of matter concerned.

It may have been felt in early times that some force of analogous nature keeps the heavenly bodies in their prescribed paths. Kepler had specific ideas about gravitation, nearly all of which were correct. He conjectured that the *virtus motrix* diminished as the distance between the bodies increased, in particular inversely as the distance. However, the mathematical tools necessary to deal with the questions at issue had not then been invented; these were the analytic geometry of Descartes and the infinitesimal calculus of Newton and Leibniz.

The possibility that the force varied inversely as the square of the distance, so that when the distance was doubled the force diminished to one quarter of its magnitude, interested Newton as well as several of his contemporaries. It was the extraordinary accomplishment of Newton to have established with the aid of the calculus that this law of force holds with a high degree of accuracy throughout nature, by applying it to the solar system, comets, tides, etc. The subsequent more thoroughgoing application to nature has required notable mathematical skill as well as extensive computation, and the agreement of theory and the observed facts has been ascertained to be nearly complete.

The Newtonian law is unparalleled in the realm of physics because it calls for the instantaneous spreading of a disturbance throughout all space. Thus, if a material object is moved suddenly, the disturbance in gravitational force caused thereby is supposed to affect instantly the most distant stars. No explanation of the law has been forthcoming which accounts for it as a secondary

[1] Lowell lectures.

result of the properties of matter and electricity. Substantially all that has been done is to state the law and deduce mathematically its many consequences.

It would be unreasonable to expect a complete explanation of a phenomenon as basic as gravitation, and yet there is much to be said that is well worthy of careful consideration. A complete explanation of any set of facts undertakes to account for them in terms of still more fundamental accepted facts. For instance, heat may be explained in this way as molecular motion, discerned in a gross statistical way by means of the senses. To whatever extent this kind of explanation may be carried, there must remain other facts, taken for granted and not explicable in the same satisfying manner. There is, however, another imperfect kind of explanation (such as is here attempted for gravitation) which may be possible. For instance, geometry can be developed from a few intuitively accepted truths into all its infinite and beautiful variety by means of systematic reasoning. Such a development gives an excellent example of the second type of explanation. Another illustration of the same type is found in the so-called analytic theory of heat, where a few reasonable assumptions, such as that heat is a measurable quantity and flows from hot to cold, yield a complete theory by logical development.

It will appear that the law of gravitation is similarly predetermined by its broad qualitative properties as an interaction between bodies not in direct contact, together with the principle of relativity present in the particular framework of the physical universe which is taken as starting point. This is true of the theories of gravitation of both Newton and Einstein. Consequently it would seem that the law of gravitation expresses in the simplest possible terms the direct purpose of nature that material bodies tend to approach one another in empty space.

In the framework of space and absolute time at the base of Newton's theories, any undisturbed body yields an attached reference space in which other undisturbed bodies move with uniform velocities in a straight line. Let us select some such space of reference. Any other space which moves relatively to the selected space with uniform rectilinear motion will serve equally well.

The type of relativity which is present in the special model forming the starting point is particularly to be noted. Here the bodies are so small and so far apart that they may be treated as point particles which do not disturb one another. The special model may be considered to be realized with high exactitude in interstellar space. Now what is the type of relativity referred to? It is that a particular space can be replaced by any other space

moving uniformly in any direction, and also that particular units of length and time can be replaced by any other units, without change in the statement of physical laws. It is natural to try to maintain such a relativity in the generalization of the special model to space and time taken as the container of interacting matter. In another form, this requirement means that the physical properties of bodies are to be thought of as independent of velocity and orientation in the selected space.

First let us consider briefly the contact forces such as arise when equal, rigid, spherical particles happen to collide. The two particles will move with constant velocities along straight lines before collision. The point P midway between their centers will do

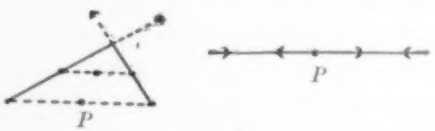

FIG. 1

likewise. Let the space of reference be taken to be attached to this point, P. Then in the equally valid new reference space, the two particles will approach one another with equal velocities in opposite directions and collide at P. It is assumed for the sake of simplicity that the collision is direct and not glancing. The recoil must be in the straight line joining the two particles, if the principle of relativity which obtains in the special model is not to be destroyed. In fact, otherwise, the result would not be independent of orientation in the space selected. Likewise, the two velocities of recoil must be equal, or there would be a physical distinction between the two directions on the line of approach. Finally, if we interpret the relativity of time in the mathematical sense that the unit of time can be changed to its negative, (*i. e.*, that any series of happenings can be described in the reverse order), it appears readily enough that the velocity of recoil must be the same as that of approach.

Thus the entire behavior under direct collision is determined, and, by reference back to the original space, it is found that the laws of collision are such as to leave unaltered the momentum and energy as well as the mass of the pair of colliding particles. By such means, with the natural and inevitable extension to gases, liquids and solids, as obtained by aggregation of molecular particles, the behavior of bodies in contact can be determined in large measure by the mere requirement that the relativity of space and time remains as extensive as in the special model.

The alternative kind of force is that which acts between bodies through empty space. Let us see how it is that such gravitational

force is determined in character by the same requirement that the relativity present in the special model be preserved.

It should be observed that the word *force* as used here and earlier has no metaphysical significance. When any particle departs from motion with constant velocity in a straight line, then, in the momentarily attached Newtonian space, the particle will be leaving its position by a definite distance in one second. Such a displacement in position for each unit of mass is the measure of the force which acts. Hence we can define force by purely geometrical methods based on a measurement of displacement from uniform motion in a straight line, and this is the definition adopted here.

Now the Newtonian analysis of space and time is incomplete to the extent that it proceeds as if light were propagated instantaneously. But such a restriction only means that the velocities of bodies are of very small magnitude in comparison with the velocity of light. In order that such a situation be maintained, it is necessary that only bodies of small mass be considered. It is, therefore, a restriction to the case of small masses and velocities.

Take first two equal spheres of small mass relatively at rest, held at a fixed distance apart by a very light rigid bar. If the bar is removed, the mutual influence hypothesized must necessarily result in a displacement of the spheres along their line of centers, measurable as a force. This conclusion follows by the principle of relativity used before. The magnitude of the force can only depend on the distance between the spheres. Unless some particular absolute unit of length exists, the force must vary as a power of the distance, as a little mathematical argument would show; the existence of such a unit of length is inconsistent with the same principle of relativity. The force can not vary directly as a power if it is to vanish when the two bodies are at a great distance from one another. It can not vary inversely as the first power of the distance, for in that case bodies approaching one another from a distance acquire indefinitely large velocities by mutual influence. Nor can it vary inversely as the third power or a higher power, for then the mere aggregation of continuous matter provides an infinite supply of energy. Thus, by very obvious requirements, the range of choice appears effectively narrowed down to the law of Newton, according to which the force varies inversely as the second power of the distance.

Although only the gravitational interaction of two small equal spheres has been considered, the principle of the superposition of small effects, widely observed in nature, is of service in the determination of the forces of interaction between any number of equal

or unequal small bodies. A simple illustration of this principle is afforded when sets of circular ripples, caused by as many pebbles striking the surface of the water at different points, meet. The height of the combined wave is the sum of the heights of the separate waves. The principle of superposition is one that holds by virtue of an inner mathematical necessity rather than an independent physical principle.

Hence the mechanical and gravitational laws of interaction are determined, once the Newtonian framework of space and absolute time is accepted, and the full relativity of that framework is insisted upon. The logical incompleteness in the preceding development of this fact is by no means to be ignored, but the fact itself seems undeniable.

One limitation in that theory arises from the circumstance that it takes no adequate account of the finiteness of the velocity of light. Accordingly, any inaccuracy in the law of gravitation obtained is likely to manifest itself when the relative velocities are high. In particular, it would be expected that, of all the planets, Mercury would deviate most from its predicted orbit, for it moves with the highest velocity of any planet under the solar attraction. Such a deviation has been observed.

Furthermore, when this framework is adopted, it is not possible to maintain the same degree of spatial relativity in dealing with electricity and magnetism. This is also to be anticipated, since light is electromagnetic, and the disregard of its velocity is particularly improper from the electromagnetic point of view. It thus becomes necessary to adopt the absolute space or ether of Faraday and Maxwell.

The diagrammatic circle of relativity may be used to illustrate the considerations adduced above. Consider the circle with the infinitely many symmetric reference lines through its center, representing the relativity which is present at the outset in the Newtonian framework. Suppose that a point in the plane of the circle is to be specified in such wise that the symmetry is not lost. The point must necessarily be the center. Or suppose that another circle is to be specified under a similar condition. It must have the same center as the first circle. On the other hand, if it is demanded that a line be laid down, the symmetry is necessarily destroyed. The mechanical and gravitational laws are analogous to the point and circle to be determined. The fact that these laws are in accord with the principle of relativity indicates the basic importance of that principle. On the other hand, the laws of electromagnetism are inconsistent with the principle, and so are akin to the straight line.

If the above analysis is correct, the heuristic value of the prin-

ciple of relativity for classical physics can scarcely be overestimated. With it the form of the laws of mechanics and gravitation seem predetermined, while without it these appear to be given at random. The laws of electricity and magnetism are not so predetermined, however, in that theory.

In passing to the special theory of relativity invented by Einstein in 1905, we begin with a more adequate analysis of space, time and light, and obtain a corresponding framework. Any undisturbed particle defines a particular space and time relative to itself, in which interacting matter is taken to be present. When it is required that the new, spatio-temporal type of relativity of the special model be strictly preserved, a very interesting situation results. The laws of contact action of elastic bodies can be determined by means like those available in the Newtonian case. Slightly modified principles of conservation of mass and energy, and momentum are obtained, in such wise that the theory agrees with the known facts of mechanics at the velocities found in nature.

The account given of the electromagnetic theory in empty space becomes extraordinarily symmetric with this type of relativity. The theory may be approached very readily by means of a few broad qualitative assumptions and by use of the principle of spatio-temporal relativity. The symmetry between space and time is so complete that one is justified in writing down the correct dimensional equation

$$186{,}300 \text{ miles} = \sqrt{-1} \text{ seconds}.$$

The meaning of such a mystical equation can not be elaborated here: it indicates a formal symmetry between the properties of space and of time. This peculiar kind of symmetry is found throughout the theory.

If now we proceed to consider the interaction of bodies at a distance, it appears that, in the case of sparsely distributed matter at rest in some space, the law must be of the Newtonian type for the very reasons advanced before. The appropriate extension to the case of matter in relative motion may be obtained by the so-called principle of the permanence of mathematical form. In applying this principle, the simplest law is sought which is consistent with the principle of relativity and which reduces to that of Newton for such a static distribution of matter.

Any beginner in algebra who knows that a^1 stands for a, a^2 for a times a, a^3 for a^2 times a, etc., sees that a law of combination by addition of exponents holds, so that a^2 times a^3 equals a^5, for instance. If asked how to interpret $a^{1/2}$, he observes that by the same law of combination $a^{1/2}$ times $a^{1/2}$ ought to be a^1 or a. Hence he infers by the principle of permanence of mathematical form that $a^{1/2}$

ought to stand for the square root of a. This principle has been found of the greatest value for heuristic purposes, and can be extended remarkably.

The law of gravitation so obtained will not account for the anomalous behavior of the planet Mercury. If it were not for this deficiency it is probable that the general theory of relativity of 1915 would not have been advanced by Einstein, since the elegant special theory of 1905 possesses the same degree of generality in its principle of relativity as the theory of Newton, and yet includes electromagnetic as well as mechanical and gravitational phenomena.

The qualitative explanation of gravitation, as far as it has been attempted here, indicates that the essential element in any new approach is likely to lie in the use of a better spatio-temporal framework. Concerning any available framework a good deal may be said in advance. In particular, if it is desired to retain anything of the older theories, it will certainly be necessary to hold to the notion that the totality of physical events corresponds to a "four-dimensional space-time continuum." This statement only means that events can be specified by means of three space numbers and one time number.

It was the mathematician Minkowski who pointed out in 1908 that, in its aspect of mathematical form, the space-time continuum of the special theory of relativity is highly analogous to ordinary space; in fact it *is* ordinary space (in the same mathematical sense as that in which the mystical equation written above holds) except that an additional dimension is present. The events are the points, the collections of events at a single particle, called "world lines," are the straight lines, the local time elapsed between two events at a particle is the distance between them, and the space appertaining to a particle at any instant of its time is a three-dimensional "hyperplane" perpendicular to its world line.

Now, in a sense to be explained in a moment, ordinary space is a continuum without "curvature."

It is natural to ask in consequence: Can not the framework of space-time be made more flexible so as to correspond to a continuum with curvature? The question may be restated as follows: Can not a space-time framework be used which bears to the framework of the special theory of relativity the same general kind of relation as a curved surface does to a plane? It is clear that this involves a necessary requirement that each small part of the new space-time is like the space-time of the special theory in the same sense as a small piece of a curved surface is like a plane. There seems to be little doubt that Einstein's general theory of 1915 took its origin in some such line of thought as that just indicated.

A more physical statement of the central idea of the new theory may be formulated as follows: Consider an elevator cage dropping freely toward the earth. The effect of the gravitational force of the earth appears thereby completely done away with. For example, a ball thrown in the cage will describe a straight line relative to it, just as if the cage were in empty space remote from matter. This fact suggests strongly that the space and time of any one small reference particle in empty space are the same as of any other in physical properties, and that these properties have no explicit reference to gravitation. From such a point of view, gravitational effects arise because of the fact that every part of a body tends to follow a natural path, except as it comes into juxtaposition with other parts of the body.

The meaning of this interpretation may be made more apparent in another illustration. Consider a fly on a horizontal merry-go-round. The merry-go-round will have the same physiological effect on the fly as if stationary and inclined to the horizontal, the angle of inclination being dependent upon distance from the center, and increasing with the distance. In this way a pseudo-gravitational effect is produced by the conflict between the natural motion of the merry-go-round and the natural motion of the fly.

It is evident that the relativity of physical properties to the particular particle in empty space can not be complete. For example, in the dropping elevator cage a magnetic needle will still point toward the north. Einstein requires relativity to hold to the extent that measurements with a small clock and measuring stick can be properly made. In other words, he assumes that the familiar relations between space, time and light hold at every small particle in empty space.

The new spatio-temporal framework is by no means completely determined by the single requirement that it is comparable to a spatial continuum. Each little part of it may be like the space-time of the special theory, in the same sense that a piece of a curved surface is like a plane, and yet a great deal of arbitrary adjustment is still possible. To effect the determination of the space-time continuum, it is necessary to discuss its intrinsic properties which, like those of any surface, hinge upon the important but technical concept of "curvature."

Consider the geometry of the plane. It may be developed independently of the fact that the plane is a part of three-dimensional space. For example, a straight line might be defined as the shortest path in it. If this kind of approach is made, a conical surface can be treated in exactly the same way as a plane, for it has precisely the same internal properties as a plane. To demonstrate the fact,

it is only necessary to unroll the conical surface upon the plane. The geometry obtained indicates that the plane is similar to itself in all its parts, to the extent that, if distances are reduced by half, the plane has the same properties as before.

Now consider the geometry of the surface of the sphere in a similar spirit. The shortest line between two points is an arc of a great circle on the sphere. Furthermore, all parts of the sphere are alike just as all parts of the plane are. Angles have the same significance as in the plane.

Nevertheless, there is a characteristic difference, for the sphere is not similar to itself; for instance, if the radius of the sphere is doubled, the surface of the new sphere can not be fitted upon the old one without distortion of distances. The curvature of the sphere is measured by the extent to which the property of similarity of figures fails to hold; the plane has no curvature, and is thus flat, from this point of view.

If we consider any other arbitrary surface, like an ellipsoid, it will depart from similarity to itself at each point by an extent measured by the curvature. This curvature has nothing to do with the ellipsoid thought of as situated in three-dimensional space, but is a quantity fixed by the internal properties of the surface.

In the same way the curvature of a spatial continuum of more than two dimensions can be defined by its internal properties.

Einstein requires that space-time be as flat as possible away from matter without degenerating into the flat space-time characteristic of his special theory. This is entirely akin to the requirement that an ordinary surface not a plane contains as many straight lines as possible. The solution of this more elementary problem is indicated in the figure shown herewith. Likewise he requires space-

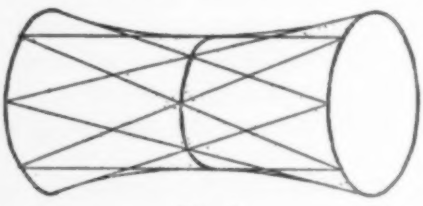

FIG. 2

time to have curvature where matter is. It turns out that space-time is satisfactorily prescribed by means of these two requirements.

Gravitational phenomena are now explicable as the inevitable result of this curvature. More concretely, the fact that two bodies in empty space tend to approach one another is comparable to the fact that any two great circles on a spherical surface will intersect one another. The new general theory obtained explains even the

anomalous gravitational behavior of the planet Mercury, and has been widely accepted on the basis of this and other experimental evidence.

It is very important to understand the essential modification which the principle of relativity undergoes in its extension to the highly fluidic space-time of general relativity. The space and time of a particle in empty space near matter are required to possess *very nearly* the same physical properties as of a particle remote from matter, so that, in particular, gravitational phenomena relatively to the particle are absent. It can not be and is not demanded that these properties are *exactly* the same. However, if the units of space and time selected are very small and diminished in the same ratio, so that very rapidly running clocks and very small measuring sticks are used, a Lilliputian universe results. In this universe gravitational phenomena disappear, and the laws of space, time, of matter and electricity, will be those of the special theory of relativity already considered, and the same for every reference particle.

The spatio-temporal system of any particle becomes of less and less consequence for more and more remote events. For this reason, if a well-balanced view of the physical universe is sought, it does not appear desirable to regard these individual spatio-temporal reference systems as of unusual importance. In other words, the selection of a reference system becomes to a large degree arbitrary.

It is in this fluidic property of the general theory that its difficulty resides. Near any particular event in space and time, experiments may be carried out with security at any small freely moving body; local distances, lapses of time, densities, pressures, temperatures, etc., may be treated by the usual methods, applied as if the body were at rest. The general laws of each microcosmic part will be those of the special theory, and yet there will be a slight macrocosmic deviation, caused by the presence of matter and the resultant curvature of the four-dimensional space-time continuum. Gravitational phenomena appear as only the direct manifestation of this curvature.

It is extremely natural from a philosophic point of view to require matter to condition space-time, for the physical determination of space and time is always through the intervention of matter.

A still more fluidic framework of space and time, based on the notion of "affine connection," has been introduced by Weyl, and developed much further as the "geometry of paths" by Eisenhart and Veblen. Recently it has formed the principal basis of attempts at even more complete unification of physical law by Eddington, Weyl and Einstein.

The general relativity of Einstein is connected with his special optical relativity, the mechanical relativity of Newton, and the geometrical relativity of Euclid in a very interesting way.

Suppose that we consider the general theory when matter is very sparsely distributed. Then the framework reduces to that of empty interstellar space, and the small gravitational effects noted will be those appropriate to the special theory or will be negligible. The principles of optical relativity will hold.

Now suppose, furthermore, that matter and electricity are moving with such low relative velocities that the velocity of light may be taken as infinite by comparison. Then, according to the general theory, electromagnetic phenomena disappear, and the *régime* of the mechanical relativity of Newton sets in, and his law of gravitation will be valid.

If also the rotational velocities and internal pressures are so small that to all intents and purposes material bodies are continually in undisturbed motion, the geometrical relativity of Euclid holds.

The mathematical working out of the new theory is not a simple affair, despite the simplicity and unity of the fundamental point of view which has led to it. This is not at all different from the circumstances attending previous theories in classical physics, for example, the theory of elasticity. Thus, ordinarily the tuning fork is considered to be a rigid body. It is only in this way that it is visualized with any success. However, the very property which makes it a useful instrument is that, when struck sharply, it will vibrate and communicate its elastic vibrations to the air, and thence to the eardrums, and excite the sensation of a musical sound of definite pitch. The manner in which it vibrates is exceedingly complicated, and varies according to the way in which it is struck, although experiment shows that the pitch of the fundamental note is not thereby perceptibly altered. The determination of the exact mode of vibration of its several parts has never been made. Although theoretically possible by means of sufficiently extensive computation, provided the tuning fork is idealized as a so-called perfectly elastic body, yet it is to all intents and purposes impossible of accomplishment. It is not even possible to explain its general behavior save by elaborate theoretical considerations, nor to specify the fundamental note in advance by any formula. And, if it were desired to deal directly with the assemblage of atoms and electric charges constituting it in actuality, the vibrational properties would appear as average effects of enormously complicated interactions of very large numbers of elements. Hence, even here, the reality is found to be so complicated as to be beyond the power of man to conceive adequately.

Simplicity and unity in the fundamental processes and yet an infinite complexity in their combinations seem more and more to be clearly manifested in nature.

Is the Einstein synthesis in any sense ultimate? That may be held to be exceedingly doubtful. The special model of interstellar space empty save for point particles, with which Einstein begins, is not a correct one, since there do not appear to exist point particles, but merely smallest elements, called atomic nuclei and electrons. Without a true model as a starting point, it does not seem likely that a final conception of the physical world can be arrived at by a process of generalization. The advances in recent years in the domain of physics indicate that we are just beginning to discover the laws of the atom. In fact, we have been compelled to proceed from the evidence of our senses, and thus have observed laws which are the statistical effect of inconceivably numerous elementary processes hitherto beyond our ken.

His new theories are a great step in advance, for they bring together in a remarkable way the laws of nature so far obtained. In them, gravitation appears as the law of macrocosmic interconnection, caused through curvature of space-time by matter, while the spatio-temporal relativity of non-gravitational laws is maintained in the microcosmic domain.

TWO EMBRYOS FROM ONE EGG[1]

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EXPERIMENTAL embryology, or, as it is better known, developmental mechanics, started on its class-conscious career about thirty-five years ago, and its infancy is remembered chiefly for two events. The first of these was Roux's discovery (1888) that a half embryo develops from one of the first two blastomeres (cells) of the frog's egg when the other blastomere is injured but present. The second was Driesch's discovery (1891) that a whole embryo develops from each of the first two blastomeres of the sea urchin's egg when they are separated from each other. The latter discovery was followed by a study of the eggs of other animals and led to the apparent paradox that in some animals a whole embryo of half size develops, and in other animals a half embryo develops from each of the isolated blastomeres. These results were idealized as two contrasting schemes of development, and far-reaching philosophical speculations were based upon them. Echoes of the controversy that followed may be heard to-day, although interest in them appears to be on the wane. Novel as were the results themselves, it must be admitted that they have not led to the solution of any of the fundamental problems of development. They served, however, a useful end in calling attention once more—for His had attempted to do this already in 1874—to the scientific problems of embryology from which students of embryology had been diverted since 1859 by over-attention to the historical side of the subject. It is not my intention to enter here into the conflict of opinion that arose between vitalist and mechanist, for even were there any profit in doing so, which I doubt, my object is to review the facts from a different angle rather than to raise philosophical and controversial questions.

It has been found that the isolated blastomeres of sea urchins, of certain hydroids, of a nemertean, of amphioxus, of a fish, of triton and of the frog give rise to whole embryos;[2] while the isolated

[1] Chapters from Experimental Embryology, V.

[2] Kleinenberg ('78) described a process taking place in an earthworm's egg at the end of cleavage by which two embryos result from one egg, or else two embryos partially united (twins). Vejdovsky ('88) has also described the development of twin embryos from the eggs of the same earthworm (*Lumbricus trapezoides*). A reexamination of this case is desirable. There are some features in the development of these eggs that suggest the possibility that its peculiarities may be due to the earlier fusion of two eggs with subsequent separation into two parts as the cleavage progresses. If this should prove to be the case the outcome would not be so difficult to bring into line with other results.

blastomeres of ctenophors, molluscs and ascidians give rise to half embryos. Before attempting to discuss whether or not there are any peculiarities in the development of these types that furnish any hint as to why in the one case whole-development takes place, and in the other half-development, it will be profitable to pass in review a few typical instances of each kind, because we shall find that the differences are not as sharp as is generally supposed.

One negative conclusion is, however, obvious, namely, that there is no relation between the systematic position of the animals, whether "high" or "low" in the scale, and the mode of development of their isolated blastomeres; for there is a hydroid and a vertebrate in one group, and a ctenophor and an ascidian in the other.

The Development of Whole Embryos from Isolated Blastomeres

The sea urchin was the first type in which it was shown that isolated blastomeres produce whole embryos. Driesch ('91) shook apart the blastomeres and followed their development. The method that he used to separate the blastomeres was one that had been earlier made use of by O. and R. Hertwig. They found that if the eggs of the sea urchin are violently shaken a few times in a small tube, half-full of sea water, the eggs may be broken into pieces. These pieces soon round up into small spheres, and if sperm is added some of the fragments segment. This same method, with one modification, was used by Driesch to separate the first two blastomeres.

If the sea urchin's eggs are fertilized and then after a minute or two are gently shaken, so that they are not broken, the fertilization membrane that has formed at the moment the sperm pierced the surface of the egg is shaken off the egg. This procedure makes the subsequent separation of the two blastomeres, when the egg has divided, quite easy. This separation is brought about by again shaking the eggs when at the height of their division. The isolated blastomeres are then picked out for further study. Each continues to segment as though in contact with its fellow. The cleavage is strictly partial (Fig. 1, a^1, b^1, c^1). In other words, each half divides as it would have done had it remained in contact with its fellow. (Fig. 1, a, b, c).

In the normal development a cavity appears in the center of the group of dividing cells. It first appears at about the eight-cell stage and grows steadily larger as the divisions proceed. A cavity also appears in the group of cells from the isolated blastomere, but it is at first exposed to the exterior on one side. Later the cells

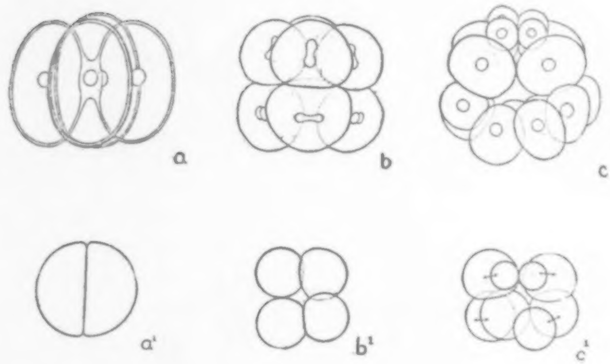

FIG. 1

around the margin of the open cavity move over it so that it soon comes to lie in the center of the group of cells as in the normal embryo. At the time when the cleavage process has temporarily slowed down, and the cells have become ciliated (blastula stage) the half-embryo resembles in all visible respects the normal embryo of the same age—except in size. If the number of its cells is counted, it will be found that half as many cells are present as in the normal embryo of the same age, and that the cells and nuclei have the same size in both. In this respect the half-embryo is not proportionate, since its cells are relatively twice too large. Half as many mesenchyme cells are present in the half-gastrula as in the normal, and each cell is as large as in the normal embryo. The turning in at one pole, to produce the gastrula stage, takes place in the half-embryo (Fig. 2, b) in the same way as in the normal embryo (Fig. 2, a). A pluteus of half-size (Fig. 2, b¹) develops that is like the normal (Fig. 2, a¹) in all its characters.

The isolated blastomeres of Amphioxus also produce whole embryos (Wilson '93, Morgan '96). The eggs in the two-cell-stage can be easily shaken apart without rupturing the jelly that surrounds the eggs, and since the interior of the jelly is a large fluid space, the two isolated blastomeres of the same egg may both be kept under observation. The halves develop into whole embryos of half size (Fig. 3, b, b¹), although, as in the sea urchin also, the cells are as large as in the normal embryo, but only half as numerous.

In triton the results are in part the same as in Amphioxus, in part different. The first cleavage plane of some eggs corresponds to the median plane of the embryo. If the blastomeres of such eggs in the two cell stage are constricted by means of a loop of hair tied around an egg in the plane of cleavage and later tightened so that the halves are separated (Fig. 4, a), the halves will develop each into a whole embryo (Fig. 4, b, b¹) (Herlitzka '96, Spemann

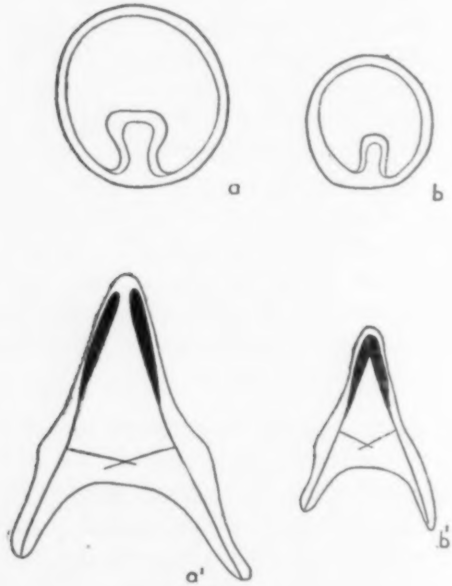

FIG. 2

'01, '03). In other eggs of triton the first plane of cleavage is at right angles to the median plane of the body of the embryo. It corresponds approximately to an imaginary cross-plane between the anterior and posterior halves of the embryo. If a loop of hair is tied around such an egg in the plane of the first cleavage and tightened until the two blastomeres are gradually separated, the halves give different results. From one blastomere, that may be called the anterior one, a whole embryo develops, or at least one that approaches a whole embryo. From the other blastomere, the

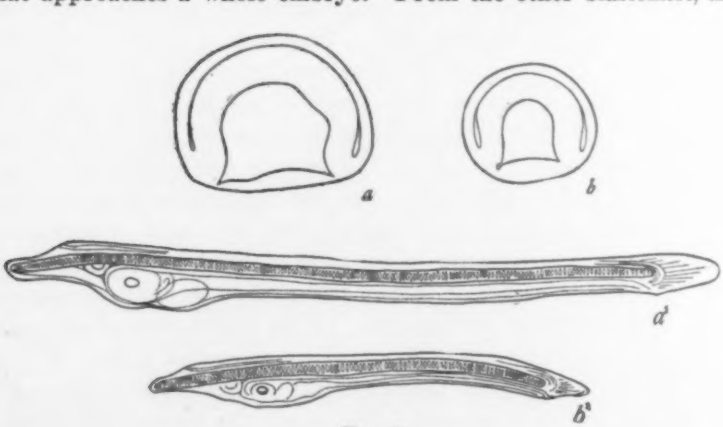

FIG. 3

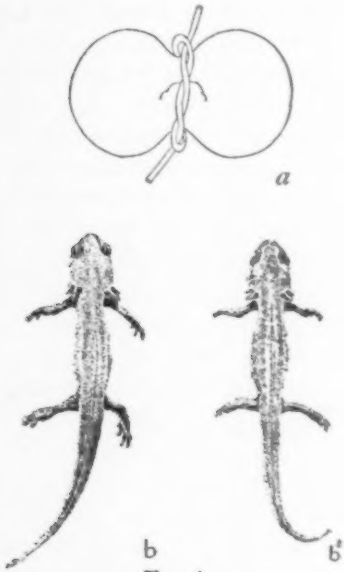

FIG. 4

posterior one, there develops a structure that to some extent resembles the earliest stages of the posterior half of a triton embryo, but it develops no further.

The differences in the results just described are significant and help us to understand in one respect at least the more general differences shown between those eggs that give whole embryos from isolated one half blastomeres and those that give half-embryos. Here, from one and the same egg, both results happen according as to whether the first plane of cleavage does or does not correspond with the median plane of the body that is foreshadowed in the first division of the egg. It will be worth while, therefore, to examine this case somewhat more in detail.

It is very probable that at the time of fertilization changes take place in the triton egg that are like those known to take place in the frog's egg. In the latter, extensive movements of material occur that become visible on the surface by the development of the so-called gray crescent. This crescent appears near the equator of the egg and indicates the position on the egg where the dorsal lip of the blastopore will later develop. It is through the center of this crescent that the first plane of cleavage of the frog's egg passes. The crescent is visible, owing to a shift in the pigment that lies in the protoplasm beneath the surface. If the pigment were less in amount, or more superficial, the shift in the protoplasm might pass entirely unnoticed. If these same changes take place in triton, it is

possible to give a plausible account as to why a different result follows when the first plane cuts through the crescent (as it does as a rule in the frog), and when it cuts the egg in two at right angles to this plane as it often does in triton. Let us consider each case separately. When in triton the first plane of cleavage cuts the imaginary crescent into symmetrical halves each half has half the crescent. The crescent is the initial point around which the subsequent development takes place. Each isolated blastomere has half of this region around which the subsequent changes take place. Some sort of readjustment must occur in such halves either before or at the time of the formation of the dorsal lip, so that the half material assumes a more symmetrical shape and becomes a whole or in other words a new median plane develops in the half crescent and whole development follows.

In the other case, where the first plane of cleavage of the triton egg is at right angles to the crescent, one of the isolated blastomeres contains all the crescent material and the other almost none of it. The former, having in itself the center for further development, proceeds to grow over the yolk and produces an embryo. The original median plane of the crescent becomes the median plane of this embryo. Readjustments to the size of the mass must take place because the embryo that emerges is not the anterior half of an embryo but a whole embryo of half size. The posterior blastomere, on the other hand, lacks the crescent, or at most has only the ends of its lateral wings; hence, lacking a center of development, it soon comes to a standstill.

This analysis, while superficial in certain respects, may help to make clearer the difference in the two cases under consideration. Viewed in this way, the development of the isolated blastomeres in the two types is not due to any fundamental differences, but to certain changes which have taken place in the egg before the first cleavage occurs—changes that have an important bearing on the future possibilities contained in different parts of the egg.

The Development of Half-Embryos from Isolated Blastomeres

The development of isolated blastomeres of the egg of an ascidian (Ascidiella) was described by Chabry as early as 1887. He accomplished his purpose by puncturing one of the blastomeres with a fine glass needle carried on a micro-dissection instrument. The apparatus was so constructed that by means of screws the needle could be swung into any desired position and then pushed forward through the egg membrane and made to pierce a selected cell. The punctured cell absorbed water, swelled up and died. The needle was withdrawn and the development of the remaining cell or cells was studied.

Chabry pointed out that the developing blastomere produces the same parts of the embryo that it would have produced had it remained in contact with its fellow. He realized the practical value of his method as the following statement shows:

> There are two methods by which the lineage of a blastomere may be discovered, the first by direct observation, the second by destroying a blastomere. Both have led me to the same result but the former is limited in its application while the second is rapid and more generally applicable. In this way I have determined with certainty that the eye is a product of the right anterior cell of the four-cell stage and I have found similar evidence for other organs—the otolith, the notochord, the atrium and the adhesive papilla. However, a secondary effect enters in to disturb the simplicity of the method but constitutes in itself an important phenomenon that calls for new experiments. It is, in effect, that by the death of a cell the potency of the survivors is changed so that they may give rise to parts which they do not otherwise produce.

Chabry's figures of the larval tadpoles that develop from the one half and three fourths blastomeres look like whole embryos in most respects. They do not show, as have later studies, that the tail muscles and mesenchyme are lacking on one side, which is to-day regarded as the most diagnostic feature of the ascidian half-embryo. On the other hand, Chabry pointed out that the adhesive organs and atrium are present only on one side. These are as distinctively bilateral structures as the musculature of the tail.

Several years later Driesch ('95) studied the development of isolated blastomeres of another ascidian (Phallusia) and interpreted the resulting embryos as wholes. He supposed that Chabry had also obtained whole embryos. Crampton ('97) also examined the isolated half-blastomere of an ascidian (Molgula) and found that the cleavage is strictly partial but somewhat obscured by the rearrangements of the cells. He concluded that Driesch was entirely correct in regard to the development of a nearly complete larva from the half-blastomere.

The later work of Conklin ('05) on still another ascidian (Styella), proved beyond question that Chabry's interpretation of the larvae as part structures was essentially correct. Conklin followed in greater detail the cleavage of the isolated blastomere, and showed that it is partial (Fig. 5, c). He made out that the cells give rise to the same parts (Fig. 5, d) that they produce in normal development (Fig. 5, b). His results also show, as had the earlier observations, that the embryo is not in all respects a half-structure. Several of the organs are, in fact, not far from whole structures. For instance, the digestive tract is a closed tube, not quite symmetrical, perhaps, but nearly so; the nerve cord is a closed tube lying in or very near the middle line, and the notocord, as in the

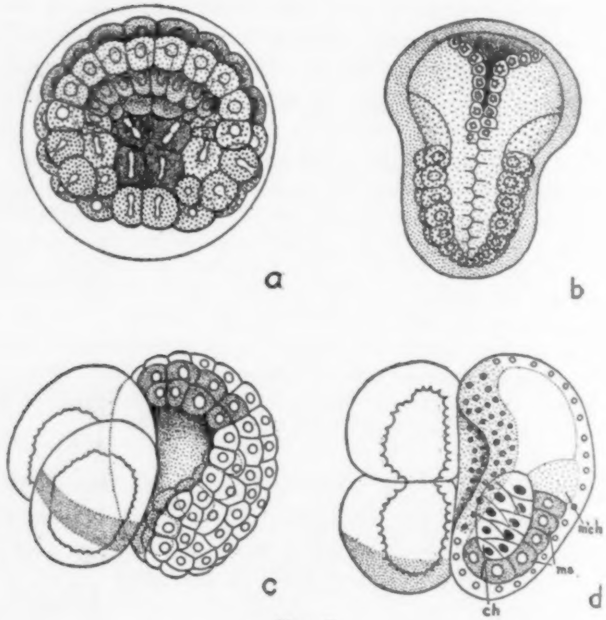

FIG. 5

normal embryo, consists of a single row of cells; it forms, in fact, a whole structure. The mesoderm of the tail (Fig. 5, d, ms), however, that is lateral to the neural tube and notocord is strictly a half-structure. From the mode of origin of its cells it would not be easily possible for the mesoderm to pass over to the other side. The atrium and the adhesive discs are also half-structures in the sense that they are present only on one side as Chabry had observed, although each is of course as complete in itself as in the whole embryo. It may be said, therefore, that, while a half-embryo develops from the isolated blastomere of the ascidian egg, there is nevertheless an evident approach to whole structures of half size in three of the important systems of the body. In these latter respects such embryos would pass for wholes were not the half-structures of more lateral organs in evidence.

Chun ('77) found in the plankton a few embryos of the ctenophor, Eucharis, within the same egg membrane, each of which had four rows of paddles (instead of eight) and one tentacle instead of two. He surmised that they had arisen by the separation of the first two blastomeres through agitation of the waves and that each cell had given rise to a half or nearly half-embryo. He established his supposition ('92) by shaking eggs of Eucharis while in the two cell stage.[3] A few years later the experiment was repeated by

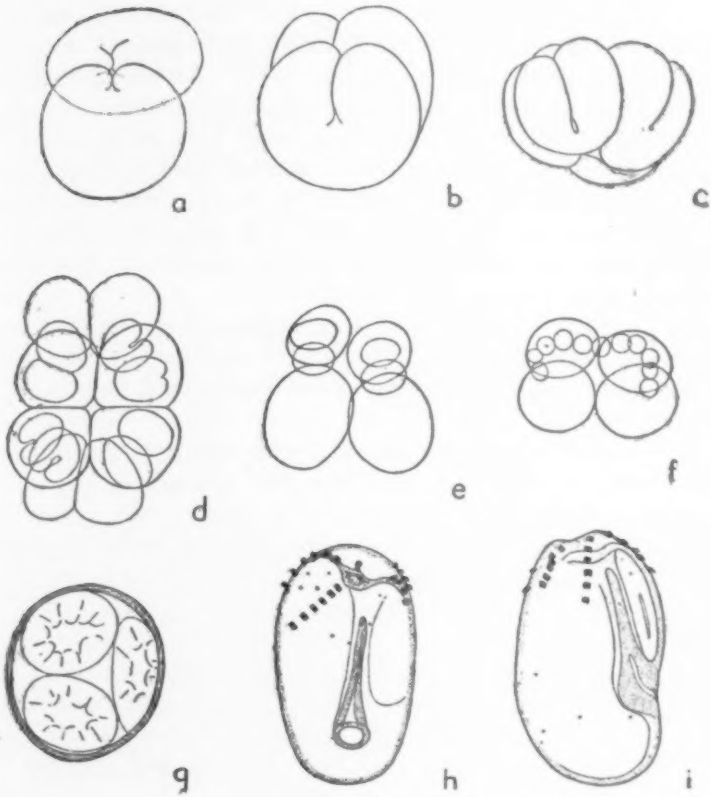

FIG. 6

Driesch and Morgan ('95) with the larger egg of another ctenophor, Beroe, and half embryos were also obtained from this egg.

The early cleavage stages of the normal egg of Beroe are shown in Figs. 6, a–d. The egg divides into two equal cells. Each cell again divides in a plane at right angles to the last. The third division is somewhat oblique, giving rise to 8 cells that are nearly in one plane (Fig. 6, c). Then from each of the 8 cells a small micromere is given off (Fig. 6, d). It is from derivatives of these 8 micromeres that the 8 rows of swimming paddles develop. This has been shown by removing one or more of the micromeres or by displacing them with respect to the other cells (Fischel ('98) Yatsu ('12)). The results show that even at the two cell-stage certain changes have taken place that proceed in each half as though it were independent of the changes going on in the other half.

[3] Roux's half-embryos of the frog ('88) had developed in the presence of the other injured half, and the results were undoubtedly affected by the presence of the injured blastomere, as his results indicated and as later results have proven.

It was further shown by Driesch and Morgan, and later confirmed by Fischel ('98) that the ctenophor half-embryo is somewhat more than a half structure (Fig. 6, g, h, i). The ectoderm, for instance, covers the whole surface; there is a single tubular esophagus somewhat excentric in position, and instead of two gut-pouches (i.e., half the normal number), there is a smaller third pouch generally present. Whether the apical sense organ is something more than a strict half was not determined. But with these reservations the embryos from the isolated blastomere may be said to represent in certain striking respects a half structure.

The isolated blastomeres of four molluscs have been studied; Crampton ('96) has studied the isolated blastomere of Ilyanassa, Wilson ('04) that of Dentalium and of Patella, and Conklin ('05) that of Crepidula.

The normal egg of Ilyanassa divides into two nearly equal halves (Fig. 7, a, b). A yolk lobe (yl) appears in one of the blastomeres (CD) as the first division is taking place. When this blastomere is isolated it cleaves as part (Fig. 8, a, b, c, d) and later produces the primary mesoderm cell (Fig. 7, f, d^4), while the opposite blastomere, AB, when isolated (Fig. 8, e, f, g, h,) fails to produce this cell. It is to be expected, therefore, that the former might produce an embryo much more nearly whole than the latter that lacks this important cell from which nearly all the middle layer organs develop. The half embryos of Ilyanassa died, however, without passing beyond the later cleavage stages, so that the characters of the two embryos are not known.

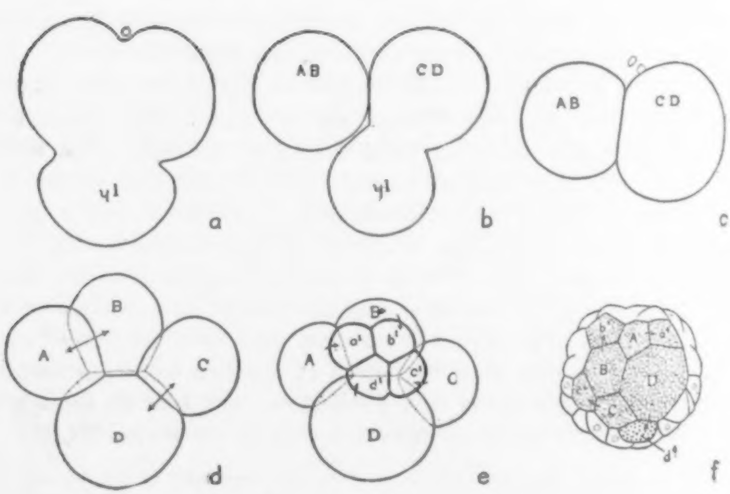

FIG. 7

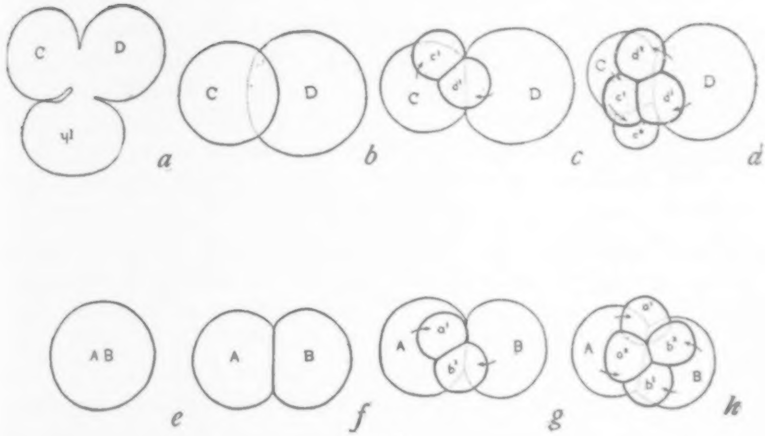

FIG. 8

In Dentalium the fate of both the CD and the AB blastomeres has been followed somewhat further. The normal cleavage is shown in Fig. 9 a–f; that of the isolated CD blastomere in Fig. 10 a–f; and that of the isolated AB blastomere in Fig. 11 a–d. The normal swimming larva (trochophore) is shown in Fig. 12 a, b; the half embryo from the CD blastomere in Fig. 12 c; and the half embryo from the AB blastomere in Fig. 12 d. Wilson ('04) found that both the AB and the CD isolated blastomeres (Fig. 10 and Fig. 11) cleave as parts, *i.e.*, each as though still in contact with its fellow. Each gives rise to a swimming larva, but the two differ in

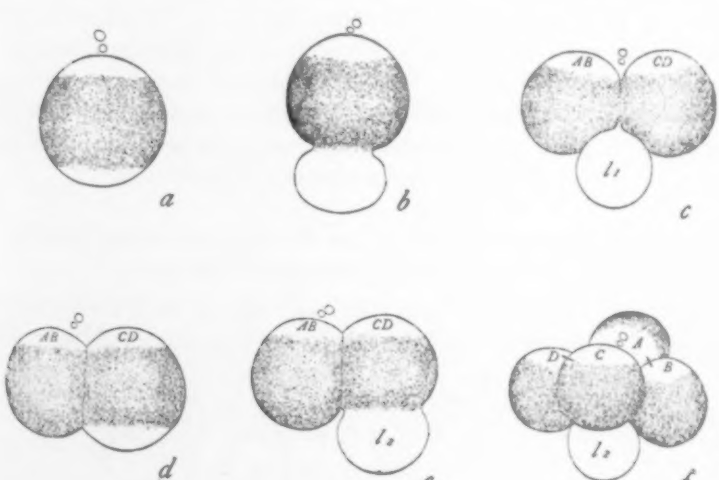

FIG. 9

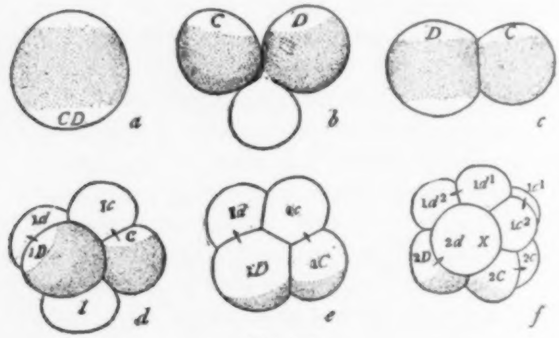

FIG. 10

certain respects. The AB larva lacks (Fig. 12, d) the apical tuft of cilia, whose presence is in some way connected with the presence of the yolk lobe. The CD larva (Fig. 12, c) has an apical tuft. The AB larva also lacks the region behind the circle of ciliated cells. How far its absence is due to the absence of the d^4 cell, directly or indirectly, has not been shown. The CD larva has a post-trochal region. Superficially, at least, it is not partial but complete, but as yet we do not know whether the mesoderm derived from the 4d cell forms a symmetrical or an asymmetrical structure inside of this embryo. Outwardly at least, the CD embryo approaches a whole larva of half size, but if we apply to this case the same criteria that have been insisted upon in the case of the half-ascidian embryo we should be obliged to confess that we do not know whether the half Dentalium CD trochophore is a half or a whole structure. Much less could it be said that the AB trochophore is a whole embryo if it lacks all the mesoderm normally derived from the 4d cell. The conventional distinction between whole and half embryos has here very little meaning, owing to the unilateral origin of the mesoderm that comes in the normal embryo only secondarily to have a right and left distribution.

THE DEVELOPMENT OF THE HALF BLASTOMERE WHEN LEFT IN CONTACT WITH ITS INJURED PARTNER

The experiment that Roux ('88) carried out by injuring one of the first two blastomeres of the frog's egg and the conclusions that

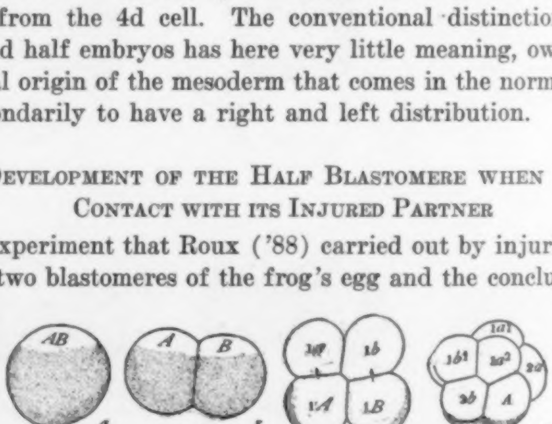

FIG. 11

he drew from the results occupied the forefront of the earlier discussions concerning developmental "mechanics." The later experiments of the same sort by Endres and Walter ('95), Morgan ('04) and Brachet ('05) have confirmed Roux's main result, while other somewhat different experiments by Schultze ('94), Wetzel ('95) and Morgan ('95) have led to conclusions that are very different from those that Roux reached from his evidence.

Roux stuck one of the blastomeres with a hot needle. Its development was for a time delayed or entirely suppressed. The other, uninjured blastomere continued to develop as though the injured half were also proceeding along the same path. A half-blastula stage (Fig. 13, A) followed by a half or nearly half embryo developed in intimate contact with the injured half (Fig. 13, B). Similar embryos have also been reported by Endres and Walter, by Morgan and by Brachet, and even some of those described by Oscar Hertwig are obviously of the same sort, despite the fact that Hertwig gave a different interpretation to them as well as to all embryos that develop under the conditions of this operation (see below).

There are three questions connected with Roux's experiment that call for further discussion; first, as to whether the embryo is more than half; second, as to whether the result is due to

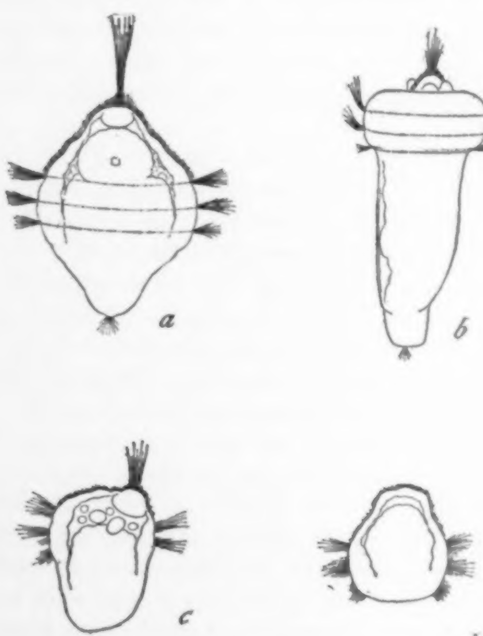

FIG. 12

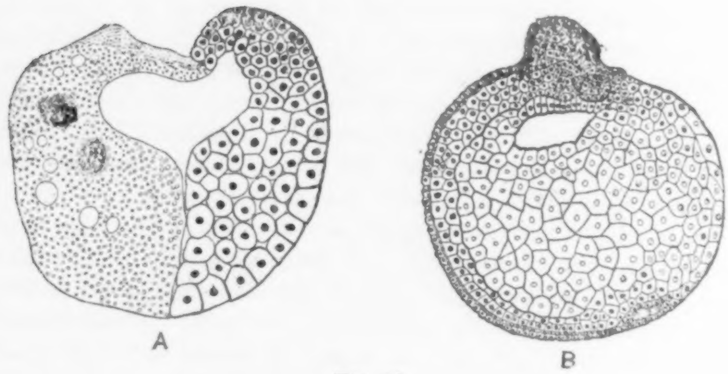

FIG. 13

the injured blastomere remaining alive; third, as to whether the injured half may at times partially develop.

(1) That the head end of the embryo is often more than a half structure is shown by several of the drawings of the embryos. Nevertheless, the rest of the nerve plate is much more nearly a half than a whole structure and from the method of the early formation in a lateral position this is perhaps to be expected. The notochord is circular in outline and may well be spoken of as a whole structure. The anterior end of the digestive tract also approaches in some respects a whole structure, although the block formed by the injured half appears to interfere with its completion. In other respects, especially in relation to the mesoderm, these embryos are practically halves.

(2) Both Hertwig ('93) and Morgan ('97) have challenged Roux's treatment of the injured blastomere as though it had been killed by the hot needle, although it should be added that when describing the subsequent changes in that blastomere, Roux recognized that it is still alive except for the streak of necrotic tissue along the path of entrance of the needle. A study, by means of sections, of the injured blastomere shows that in many of them the nucleus has not been injured; that it may subsequently divide, and that portions of the cytoplasm may split off from the rest and add themselves to the uninjured half, and in extreme cases the delayed blastomere may even catch up and produce its half. Owing to the opacity of the egg, it is not possible to follow continuously what takes place and at best the history can only be pieced together. Aside from these details the evidence shows positively that the uninjured half is alive and in intimate contact with the other half. This condition raises a series of further problems as to the possible influence of the injured on the developing half. If the unsegmented

half *remaining in its normal position* can exert the same sort of influence on the developing half as it would exert were it also dividing, the experiment tells nothing more than what was already known from the earlier observations showing that the material on one side of the first cleavage plane gives the right half of the embryo and that on the other side the left half. Other experiments to be described in a moment show that this is probably the case, but the nature of the influence remains as obscure as before.

(3) Roux has described under the name of post-generation changes that take place in the injured half by means of which the missing half may be later replaced. The account of these changes is obscure in many important respects, and necessarily so since it is gained by patching together the evidence of sections from different eggs no two of which may have had the same antecedents. My own view of the matter is that whenever the missing part reappears its development must come very largely from the delayed development of the injured blastomere. A discussion of these difficulties of interpretation would require here too much space and the conclusions would not affect the main issues under discussion.

Oscar Hertwig has given an entirely different account of what occurs where one blastomere is injured by Roux's sticking method. In a word, he thinks that the uninjured blastomere develops as a whole, except when the injury is so slight that part of the other blastomere becomes incorporated in the uninjured half. The injured blastomere, he states, holds the same relation to the developing half as does the yolk to the embryo of a meroblastic egg. In other words, a whole embryo develops with an uninclosed ventral yolk. That something like this may at times really take place is possible, I think, in the light of the other evidence given below, but I also think the comparison with the meroblastic egg is entirely misleading. If, after the operation, the egg is so placed that the uninjured blastomere lies on top of the other, then, through the rotation of the protoplasm in the interior of this blastomere, the conditions are such, as shown by other evidence, that a whole embryo, so far as the physical conditions allow, may develop from the uninjured half. In so far as the rotation of the protoplasm is incomplete, all degrees of part and whole embryos may result and the internal evidence in Hertwig's paper points clearly to some such interpretation.

Later observations have shown that each of the first two blastomeres of the frog's egg may produce a whole embryo provided the influence of the other half is changed or removed.

It was shown by Schultze ('94) that if the egg in the two-cell stage is turned over so that the white hemisphere is on top, and if

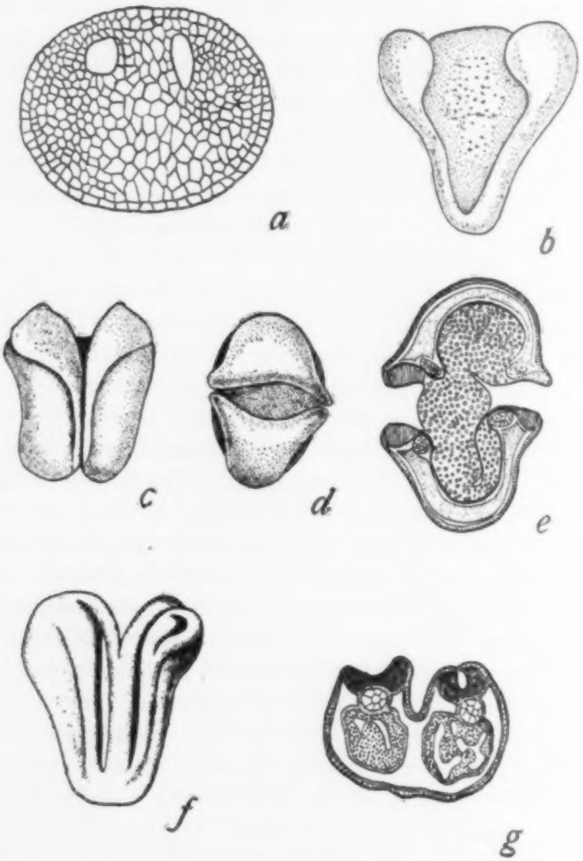

FIG. 14

the conditions have been so arranged that the egg can not turn over to its normal position with the black hemisphere above, then two whole embryos develop, one from each half. Sometimes these embryos lie side by side, (Fig. 14f) like Siamese twins. At other times they are united in their ventral surface (Fig. 14b), and at other times they are back to back (Fig. 14c, d, e). In the last, the halves are prevented from coming together by the yolk. Each embryo shows, in consequence, a spina bifida condition (Fig. 14e). Wetzel ('95) has given an account of the changes that take place in the inverted egg. In each blastomere the lighter protoplasm, now below, tends to move upward and the yolk to sink downward. The path taken by these components will depend on slight differences in the inclinations of the egg, and, correspondingly, the embryos that result will be diffierently placed in different eggs.

Each half develops independently of the other, so far as the physical conditions permit; each develops its own planes of symmetry and produces a whole embryo of half size.

The upshot of all this evidence is, that if like regions of the two eggs are separated they no longer act together as parts of a whole. This conclusion, if applied to Roux's half-embryo, may be interpreted to mean that the development of a plane of symmetry is influenced by the juxtaposition of similar protoplasmic fields, but unfortunately the evidence fails to reveal whether this is a chemical influence or only due to physical contact.

That each blastomere of the frog's egg may produce a whole embryo has been shown by experiments of Morgan ('95) and McClendon ('00). The former found that if, after injuring one blastomere with a hot needle, the two blastomeres are kept in their normal position with the black hemisphere up, a half-embryo develops. But if, after sticking, the egg is turned so that the uninjured cell is on top it gives rise to a whole embryo. McClendon ('00) found that by the combined action of a pipette and careful sticking with a cold needle it was possible to remove entirely one of the first two blastomeres of the egg of the tree frog, Chorophilus. The remaining blastomere produced a whole embryo. The operation is not possible on most species of frogs, so far tried, because the removal of the contents of one blastomere causes the other to collapse.

Conclusions

It is with some hesitation that I venture to express a personal opinion as to the interpretation of the results of the experimental work on isolating blastomeres. I find nothing in them that is particularly mysterious, *i. e.*, nothing that we may not hope in time to explain mechanically. In fact, it seems rather obvious that both whole and half development proceeds along lines that have already taken place in the preceding stages. The blastomere when isolated does not suddenly become a whole, but, as the successive stages appear, they are modelled on what has already taken place as in the normal development. Those readjustments that lead to whole organs instead of partial structures appear to involve only the same processes that take place in whole embryos in the same stages. This is particularly evident in organs that lie in the middle line. Those that are to one side of the middle line may continue their regular course of development and call for no special explanation.

This pioneer work is rather exploratory than experimental. It has been carried far enough, however, to make it seem doubtful whether we have much more to expect from a continuation of the

work along the old lines. We need for further progress to find out the physical and chemical nature of the material that causes it to take on, as each phase of development is reached, definite symmetrical patterns. The biological analysis has, for the moment, reached its goal, and the problem is ready to hand on to the physicist. We can now, I think, with profit throw into the discard the whole transcendental philosophy that has been used in describing the facts. Such terms as self-differentiation and interaction of the parts, prelocalization of cytoplasmic areas, prospective potency and the like, did no particular harm so long as it was realized that they were only names for certain observed facts, or inferences from the facts; but in so far as these expressions did not refer the phenomena to simpler or better known processes or principles, their use has played directly into the hands of the vitalist, for these words do not suggest anything with which a physicist or chemist is familiar.

ANTONI VAN LEEUWENHOEK, IMMORTAL DILETTANT (1632-1723)[1]

By Dr. L. B. BECKING
STANFORD UNIVERSITY

The microscope was invented and man began to observe strange things; the shores of a new world. At first he saw only dim and distant shadows, projected vaguely upon his consciousness. Like "the living atoms of the world" those shadows trembled before man's vision, whirled and fled.

The few that were able to look through that small magic window, the lens, felt that their eyes had seen wonders. They toiled to make these shadows into realities; until at last they were able to see them clearly—the inhabitants of a world within our world—the citizens of the microcosm.

Structure within structure, they realized, was a new expression of eternity.

Fate had decreed that a revelation of this world should come to a man of mediocre mind, but with marvellous hands and keen eyes. A humble lens-grinder, at the service of too many intellects, he laid down his observations as he made them, in a series of incongruous, chaotic, but truthful observations. Incredibly truthful observations. For few are wholly able to withstand the temptation to interpret the results according to expectations.

Truly he was a pair of eyes, a pair of hands, directed by other minds. For when his own mind tried to direct, he could produce nothing but chaos.

His work is very little appreciated because little read in the original. This is perhaps the reason why the existing biographical characterization of the man and his work give an entirely erroneous impression.

Biographers often see their subjects either too closely or from too great a distance. The account given by the loving self, the loving wife or the loving son-in-law can not but represent a carefully retouched portrait. On the other hand, the thorough but tasteless account of the historiographer describes a spectre, not a reality—an abstraction, not a vitality—the embodiment of an idea, but not the forces creating it.

[1] Lecture held for the Society of Experimental Biology and Medicine, October 26, 1923.

ANTONIUS A LEEUWENHOEK.
Regiæ Societatis Londinensis membrum.

What really matters in a biography is not the so-called biographical datum. The attributes of a creature; its birth, its growth, its offspring, its death only express the fact that it was alive and kept in this precarious condition for some time, after which it went the way of all flesh.

Biographical data are only useful to coordinate the individual in his proper surroundings. That Leeuwenhoek was married twice, that he had many children, can be found, with many other delightful details, in one of his biographies. It does not concern us here.

Modern biographies also frequently mention hereditary factors. Is the heritage as important as it seems? Nothing prevented Pas-

teur, a tanner's son, from becoming the scientific aristocrat "par excellence" of his age. Nothing prevented Leeuwenhoek, a patrician's son, from developing into an uncultured mechanician.

There are factors, inherent in the race, that breed out and force themselves into the phenotype regardless of careful selection, regardless of parental influence. They appear at certain stages in the development of a homogeneous population and determine the character of the community.

Leeuwenhoek fitted well into the surroundings of the seventeenth century Dutch Republic. His influential relatives secured a position for him—in that age of nepotism—when at forty he had failed in life, when he had neither acquired learning nor money nor power to make himself esteemed by the burghers of his native town. He was made janitor or Bedellus of the sheriff's office at Delft.

Many comments have been made by biographers on the humbleness of his position. Even his contemporaries were properly impressed by it, especially his English fellow-members of the Royal Society. They were probably ignorant of the fact that the position was a sinecure, obtained by political graft and created as a source of income for one of the renegade sons of the governing families. But the position was important because it provided for ample leisure. While his presence at the office was required, he had practically nothing to do.

Leeuwenhoek belonged to a time when the mentally unendowed collected curios and shells, when the bulb fanciers tried to attach excessive importance to relatively unimportant objects, as stamp collectors do. There is a spiritual bond between collectors and creators-of-tiny-things. The collector wants to fill an emptiness that is within himself. Creators-of-tiny-things want to kill a threatening emptiness—time. People who wait, conducted by this "horror vacui," construct absurd things. They knit and knit, while they wait for the guillotine to fall. They adorn their books with curious ornaments while waiting for the end of a lecture hour. Railroad guards, around their shanties, construct elaborate doll-gardens, and Esquimaux during the long polar night carve little figures out of walrus-teeth.

Leeuwenhoek filled, and killed, his time with the grinding of lenses. During the dreary Dutch days, when rain drizzled outside, and chill must have pervaded his "comptoir" the dilettant was slowly preparing himself for immortality.

He stayed at Delft until his death, but still he can not be compared in this respect with Immanuel Kant, who never left Königsberg. Kant had created a universe within himself. For Leeuwen-

(821)

Obſervations, communicated to the Publiſher by Mr. Antony van Leewenhoeck, *in a Dutch Letter of the 9th of* Octob. 1676. *here Engliſh'd: Concerning little Animals by him obſerved in Rain- Well- Sea- and Snow water; as alſo in water wherein Pepper had lain infuſed.*

IN the year 1675. I diſcover'd living creatures in Rain water, which had ſtood but few days in a new earthen pot, glaſed blew within. This invited me to view this water with great attention, eſpecially thoſe little animals appearing to me ten thouſand times leſs than thoſe repreſented by Monſ. *Swamerdam*, and by him called *Water-fleas* or *Water-lice*, which may be perceived in the water with the naked eye.

The *firſt* ſort by me diſcover'd in the ſaid water, I divers times obſerved to conſiſt of 5, 6, 7, or 8 clear globuls, without being able to diſcern any film that held them together, or contained them. When theſe *animalcula* or living Atoms did move, they put forth two little horns, continually moving themſelves: The place between theſe two horns was flat, though the reſt of the body was roundiſh, ſharpning a little towards the end, where they had a tayl, near four times the length of the whole body, of the thickneſs (by my Microſcope) of a Spiders-web; at the end of which appear'd a globul, of the bigneſs of one of thoſe which made up the body; which tayl I could not perceive, even in very clear water, to be mov'd by them. Theſe little creatures, if they chanced to light upon the leaſt filament or ſtring, or other ſuch particle, of which there are many in water, eſpecially after it hath ſtood ſome days, they ſtook intangled therein, extending their body in a long round, and ſtriving to dis-intangle their tayl; whereby it came to paſs, that their whole body lept back towards the globul of the tayl, which then rolled together Serpent-like, and after the manner of Copper- or Iron-wire that having been wound about a ſtick, and unwound again, retains thoſe windings and turnings. This motion of extenſion and contraction continued a while; and I have ſeen ſeveral hundreds of theſe poor little creatures, within the ſpace of a grain of groſs ſand, lye faſt cluſter'd together in a few filaments.

I alſo diſcover'd a *ſecond* ſort, the figure of which was oval; and I imagined their head to ſtand on the ſharp end. Theſe were a little bigger than the former. The inferior part of their body is flat, furniſhed with divers incredibly thin feet, which moved very

Reproductions of two pages from the Royal Society Transactions, 1676, showing that Leeuwenhoek saw aerobic bacteria in pepper infusions. See H. W. Beyerinck, Verzamelde Geschriften, Vol. V, p. 127, 1922.

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to my ſelf. This pepper having lain about 3 weeks in the water, to which I had twice added ſome Snow-water, the other water being in great part exhaled; I looked upon it the 24 of *April*, 1676. and diſcern'd in it, to my great wonder, an incredible number of little animals, of divers kinds; and among the reſt, ſome that were 3 or 4 times as long as broad; but their whole thickneſs did, in my eſtimation, not much exceed that of the hair of a Louſe. They had a very pretty motion, often tumbling about and ſideways; and when I let the water run off from them, they turned as round as a Top, and at firſt their body changed into an oval, and afterwards, when the circular motion ceaſed, they returned to their former length.

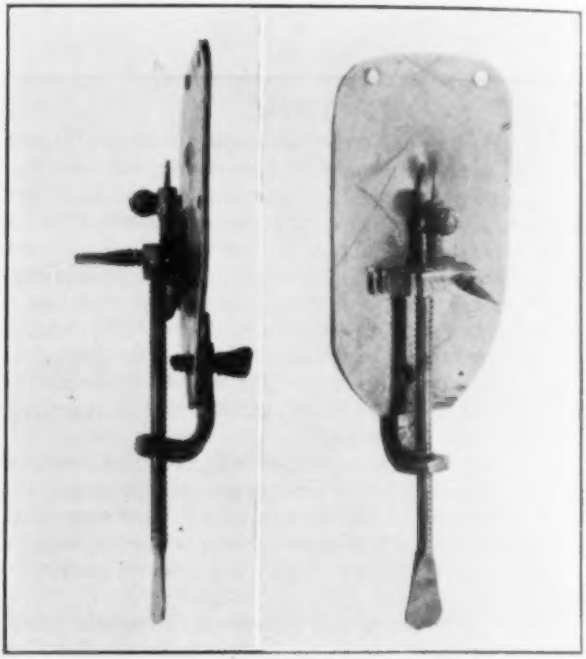
The 2*d* ſort of creatures, diſcover'd in this water, were of a perfect oval figure, and they had no leſs pleaſing or nimble a motion than the former; and theſe were in far greater numbers. And there was a 3*d* ſort, which exceeded the two former in number; and theſe had tails alſo, like thoſe I had formerly obſerv'd in Rain-water.

The 4*th* ſort of creatures, which moved through the 3 former ſorts, were incredibly ſmall, and ſo ſmall in my eye, that I judged, that if 100 of them lay one by another, they would not equal the *length* of a grain of courſe Sand; and according to this eſtimate, ten hundred thouſand of them cou'd not equal the dimenſions of a *grain* of ſuch courſe Sand.

There was diſcover'd by me a fifth ſort, which had near the thickneſs of the former, but they were almoſt twice as long.

2. The 26*th* of *April*, I took 2½ ounces of Snow-water, which was about three years old, and which had ſtood either in my Cellar or Study in a Glaſs-bottle well ſtopped. In it I could diſcover no living creatures: And having poured ſome of it into a Porcelain Thea-cup, I put therein half an ounce of whole pepper, and ſo placed it in my Study. Obſerving it daily until the 3*d* of *May*, I could never diſcover any living thing in it; and by this time the water was ſo far evaporated, and imbibed by the pepper, that ſome of the pepper-corns began to lye dry. This water was now very thick of odd particles; and then I poured more Snow-water to the pepper, until the pepper-corns were cover'd with water half an inch high. Whereupon viewing it again the fourth and fifth of *May*, I found no living creatures in it; but the ſixth, I did very many, and thoſe exceeding ſmall

ones,



FACSIMILE COPY OF THE ORIGINAL "MICROSCOPE"
in the possession of the Zoological Institute, Utrecht, Holland. Obtained by the courtesy of Dr. H. F. Nierstrasz. With this (or a similar) instrument Leeuwenhoek's chief discoveries were made.

hoek, the marshes and meadows around Delft were amply sufficient. For Kant, the earth was too small to bother with. For Leeuwenhoek it was too vast.

Strangely undisturbed by the wars that raged around him, by political upheavals, by economic disasters, we find no mention of such things in his work. In this regard he had elements of a true scientist. Science has never been concerned with the influence of the rabble or the politicians. Already seventeenth century science had its own sphere, and quietly prepared to make our civilization.

His kaleidoscopic work was pioneering—he took the first harvest from a virgin field. But he gathered only the things that appealed to his fancy, no distinct line of thought can be found in his researches.

And, therefore, although he was the first to see bacteria, yeasts and protozoa, we can not look upon him as the founder of microbiology.

Although he was the first to describe crystals of piperin and caffein, prepared by sublimation, still Leeuwenhoek can not be called the founder of microchemistry.

FACSIMILE OF THE CIRCULATION MICROSCOPE,
with which Leeuwenhoek studied capillary circulation. This microscope was designed to study the eel's tail.

Although he describes a butyric acid fermentation in a partly evacuated tube—Pasteur is the discoverer of this fermentation, and not Leeuwenhoek.

It is only the genius that can synthesize a vast group of disconnected facts under a general law, where the truthful observer only can describe and catalogue. In that respect Leeuwenhoek did not reach the mental level of a taxonomist; his descriptions were not catalogued.

It is almost impossible to form an adequate idea of this man. This strange personality—dusty as an ancient apothecary, common to a degree, erratic, uncultured, and still, by virtue of his work, chosen to be the spiritual associate of a Huygens, a Malpighi, a Swammerdam.

The uncritical praise of his commentators and biographers can only be ascribed to an insufficient knowledge of his works and that

of his contemporaries. It is said of Saint Paul that his thoughts traveled faster than his stylus. Leeuwenhoek's description of his wonder world went so far as he, without artistic ability, could possibly depict. Compare his drawings of the insect eye with those of Swammerdam; his wood anatomy with that of Grew.

Being a true "bourgeois satisfait" he didn't feel his handicaps. He rather took a pride in the fact that he knew neither French, Latin, English nor German. Still, when we look in his works for his moments of true inspiration, we find them. His masterful account of the circulation in the tail of the eel, and his critical remarks on "generatio aequivoca" stand high above the level of his average work. His account of the body louse vies in distinctness of purpose and in whimsical description with the best passages in Fabre's "Souvenirs Entomologiques." But we have to wade through many a dreary page to reach places such as these.

Fortunately, a lack of imagination has its advantages. It does not disturb or urge the mind in several directions at once. It allows long and peaceful observation. It allows Leeuwenhoek to construct 527 microscopes of gold, silver and brass.

The estimate by one of his biographers that his portrait shows traits of both Cromwell and Spinoza is far from describing the actual Leeuwenhoek. No delicate disdain, but a rather coarse doggedness is depicted in his features. The characterization as given by one of his contemporaries fits well; kind, courteous, but illiterate.

Some are born great, some achieve greatness, some have greatness thrust upon them. Leeuwenhoek belongs to a fourth category. He was but a small fragment of a broken mirror, but he reflected the greatness of nature truthfully and directly. And he became great by reflection.

THE PROGRESS OF SCIENCE

By Dr. EDWIN E. SLOSSON
SCIENCE SERVICE, WASHINGTON

THE BUILDING BLOCKS OF THE BODY

It is fascinating to stand on the sidewalk and watch a building being put up by modern methods. The materials seem to appear by magic just when they are needed. The stones, cut and numbered, are delivered in proper order. The big steel girder arrives at the moment when its bed is prepared for it. Enough bricks are always on hand to keep the bricklayers busy and not many more. Sand, gravel and cement come along in the right quantities to mix for concrete, and little, if any, is left over at the end of the day. Doubtless, it is not all such smooth sailing as it seems. The boss may have his moments of worry over delayed delivery or the premature arrival of certain material. But the system must be well arranged, for on a narrow city lot there is little room for the storage of excess stuff, and the builder must live, so to speak, "from hand to mouth."

The building of our bodies has to be run on a schedule even more closely contrived than this, and physiologists are now beginning to comprehend its principles. Flesh and blood are largely composed of a sort of substances called "proteins," of which there are thousands of different kinds; enough to go around among all the animals and give each species a particular protein of its own. But these innumerable varieties are all made up of various combinations of a comparatively small number of simpler substances called the "amino acids" of which some twenty are now known.

How many of these several sorts are needed by any particular animal, such for instance as us, is yet undetermined. Probably a dozen, perhaps half a dozen, amino acids, if properly picked, would suffice. But our food must contain at least a little of every one of the set of amino acids that are required for the building of our bodies. If one of them is missing none of the other can altogether replace it. So, too, a typesetter must have some type in every box of his case. He can not get along without a few x's and g's, even though he may have plenty of a's and e's. But if he has as many x's and z's as he has a's and e's he can not make use of them.

So a little of a particular kind of protein may be very valuable, indeed essential. But double the amount is not twice as good, may not, indeed, be any better. Professor H. H. Mitchell, of the University of Illinois, found in the feeding of white rats that the biological value of protein from various foods ranked as follows: milk, 93.4; rice, 86.1; yeast, 85.5; oats, 78.5; corn, 72.; potatoes, 68.5. Doubling the amount of any one protein did not increase its nutritive value in proportion, but the addition of another kind of protein did increase in certain cases the value of both. For instance, rats fed on corn protein alone or on milk protein alone did not thrive as well as when the two were combined, although the total ration remained the same. Since rats have been the messmates of man from time immemorial they have acquired similar feeding habits to ours.

The lesson of this for us is that we should see that we have a varied as well as an adequate diet. There is nothing found in these investigations to

DR. ELIHU THOMSON

On whom the Kelvin Medal has been conferred. Dr. Thomson, who since 1880 has been a leader in the development of the Thomson-Houston and the General Electric Companies, has made important contributions to electrical engineering.

favor these food faddists who would have us live for life on a single kind of food such as peanuts or grapes. Even if we could know precisely what proteins our body needed at the moment and had the composition of the food down pat, we would have to have scales and slide-rule at every meal to figure it out. Better leave this complicated problem to be carried on by the unconscious calculation of our digestive apparatus, which will generally come out right if supplied with the proper kinds and amounts of building materials. If any one of them is lacking the rest can not be economically utilized.

Imagine the disgust of the construction boss if he should get several loads of sand and only one sack of cement. If it were a mistake in the kind of fuel delivered it would not be so bad. If there is a shortage of anthracite, one can use coke, or briquets, or even bituminous. But concrete has to be mixed in the proper proportions if it is to stand, so the boss having no storage space has to send away the excess sand unused.

So, too, in our body building. We need not be so particular about our fuel foods. There are many kinds of sugars, starches and fats, but they are more or less interchangeable. No one of them is indispensable. The question of quality does not matter so much in this case, nor quantity either, so long as there is enough of any of them. And if we eat too much of fats and carbohydrates, as many of us do, the surplus is disposed of with comparative ease or stored up in the body as fat. It is indeed a burden to travel with so much excess luggage as some of us do but we get along.

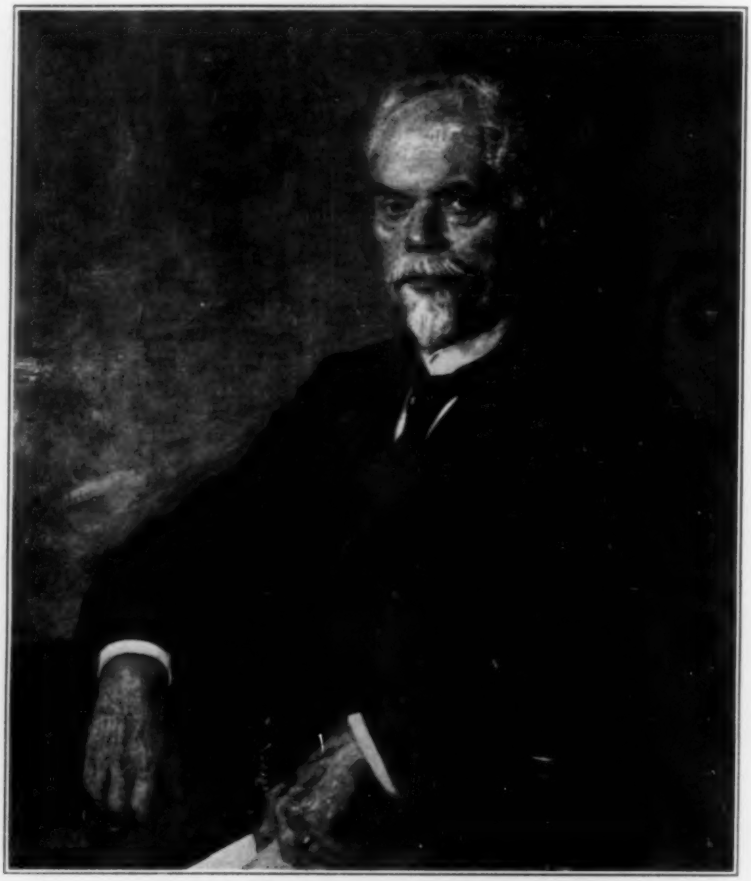
The proteins may also in part be burned up but their waste products are much more difficult to get rid of and are particularly obnoxious if allowed to accumulate in the body. So one of the delicate and difficult points in the problem of dietetics that we all have to solve every day is to see that we get proteins in sufficient assortment, quite enough of them, and yet not much too much.

TWO TYPES OF TEMPERAMENT

Are you an extravert or an introvert? That is the way the question is put to-day. The phraseology is new for it was recently introduced by Jung. But the question is old, about two thousand years old, anyhow, for Galen made a similar effort to classify mankind by temperament. He distinguished between the "sanguine," who are quick, warm, impressionable and changeable, and the "phlegmatic," who are slow, quiet and persistent. When these two characteristic types are strongly marked they are called respectively "choleric" and "melancholic."

Another old classification of a similar sort is between "objective" and "subjective" or between "energetic" and "sentimental."

Professor William James devotes the first chapter of his book on "Pragmatism" to showing how our beliefs and reactions are unconsciously controlled by our temperamental bias and from this point of view he divides people into the "tough-minded" and the "tender-minded." The tough-minded, he says, are "empiricist (going by facts), sensationalistic, materialistic, pessimistic, irreligious, fatalistic, pluralistic and skeptical," while on the other hand, the tender-minded are "rationalistic (going by principles), intellectualistic, idealistic, optimistic, religious, free-willist, monistic and dogmatical." And he says you can tell them apart because "they have a low opinion of each other. The tough think of the tender



ROBERT ERNST EDUARD WIEDERSHEIM

In whose death Germany loses its most distinguished comparative anatomist.

as sentimentalists and soft-heads. The tender feel the tough to be unrefined, callous and brutal." The tough-minded of James corresponds roughly with the extravert of Jung and the tender-minded with the introverts.

Professor Wilhelm Ostwald, of Leipzig, in his study of great scientists divides them into the "romanticists" and the "classicists." The romanticist man of science is a good teacher; genial, versatile, expansive and popular; fond of conversation and quick to publish. He jumps at conclusions, sometimes making amazing discoveries by a sort of intuition and sometimes making sad mistakes from his impatience of detail. The romanticist gets paid in current coin; in the devotion of his disciples and in honors from his colleagues, sometimes in applause and wealth from the public.

The classicist on the contrary has to put up with deferred payment. His services to science often receive no adequate recognition till his death and not always then. He pursues a single line of thought persistently and systematically for years, often without outside aid or encouragement. His mind works mathematically and logically but he may be deficient in experimental and practical ability. He is reluctant to publish and apt to be a poor teacher. Among American scientists Benjamin Thompson, alias Count Rumford, was a typical romanticist and Willard Gibbs was a typical classicist.

Professor C. G. Seligman, president of the Royal Anthropological Institute, of London, in a recent address extended Jung's categories into wider fields. We can distinguish, he says, between extravert and introvert poetry and art. In painting, Rubens and Delacroix are extraverts and Poussin and Ingres are introverts. Japan as a whole is extravert while China and especially India are introvert. Savage races as a rule appear extravert as compared with civilized Europeans. Professor Seligman thinks that in any one people the two types appear in about equal numbers, though extraverts, being more responsive and better adapted to the world, give the impression of being in the majority.

These various attempts at splitting the human race into contrasting temperament do not agree closely as to dividing lines and distinguishing characteristics, yet there is obviously a certain similarity in the types recognized. Probably the physiologist will come in with a chemical classification based upon the hormones, which seem to be much like the long laughed at "humors" of past centuries. He may, for instance, use the activity of the thyroid gland as the criterion and call the extravert a "hyperthyroid" and the introvert a "hypothyroid." He may even attempt to alter temperaments to order by injection of some coal-tar compounds, as indeed he can do now to a considerable extent.

If you can not answer the question with which we began, so much the better for you, since it shows that you have a well balanced character. Though we may safely lean one way or the other, as doubtless we all do, yet we should not run to either extreme for that way madness lies. The extreme of the extravert is hysteria and the extreme of the introvert is dementia praecox.

THE LITTLEST LIFE

"How many angels can stand on the point of a pin?" was debated by the wise men of the Dark Ages. It was a good question for debate of the sort they delighted in because they never could find out and if they could it would have made no difference to anybody.

"How many microbes can stand on the point of a pin?" is the question that interests the wise men of modern times, not for the fun of discussion but because they can find out and because our lives depend upon their finding out.

For a single microbe may be more than a match for a man in single combat in spite of their disparity in size. Compared with this, the duel between David and Goliath was a fair fight on equal footing. The man, let us say, is five feet, ten inches tall. Against him we will pit a microbe of moderate size, say a bacillus measuring only a micron in height. A micron is a millionth of a meter, or, if you prefer, a twenty-five-thousandth of an inch. Such a microbe is not afraid to tackle a man, who is 1,750,000

times as tall and 5,000,000,000,000,000,000 times his fighting weight. Yet the microbe often succeeds in knocking him out.

For although the microbe has such odds against him on the start, they do not stay so. For the microbe grows faster than the man and is quicker at multiplication. The Asiatic cholera germ, for instance, doubles every fifteen minutes. If unlimited in space and food, its progeny would equal the mass of a man in the course of some fifteen hours. That is to say, a microbe that gets a lodgment in a man might eat him up in less than a day if the man were entirely edible and provided adequate accommodations.

To return to the point. I have just tried to measure the diameter of the point of a pin but my desk rule is not fine enough so I measured the head of it. It is not one of these new fashioned round-head pins but the common metal kind and its head is two millimeters across, that is, two thousand microns. Now the bacillus of typhoid fever is two microns long and one wide. So that a thousand of them could be end to end across the pinhead or two thousand lying side by side.

But these are big ones compared with some. It was formerly supposed that water could be made germ-free by forcing it through a filter of unglazed earthenware, but it is now known that fifty distinct diseases are caused by germs so small that they will pass through the pores of porcelain. Among these are such well-known human diseases as influenza, small pox, hydrophobia and measles, and a long list of plant diseases, especially those recognizable by mosaic discoloration of the leaves.

Most bacteria measure about a micron but the one that carries the flu infection, and is known as pneumosintes, may be only a tenth of that length. The chicken plague and the mosaic diseases of tobacco are carried by something still smaller, say a fortieth of a micron.

Now when the biologist gets down as fine as this he comes into conflict with the chemist. For a single molecule of hemaglobin, the red coloring matter of the blood, is bigger than one of these creatures—if they are creatures. If they are not, how is it that they can grow and multiply and carry their specific characteristics over from one animal or plant to another? But if they are living organisms they must be largely composed of protein and the protein molecule is so large that the chemist can only allow the biologist a few hundred or at most a few thousand molecules out of which to construct the necessarily somewhat complicated machinery of these virulent bodies.

But in spite of the criticism of the chemist the biologist continues to discover minuter bodies which possess some of the functions of life. Bacteria are found to be devoured by something that d'Herelle of the Pasteur Institute calls "bacteria eaters," or if you insist upon the Greek of it, "bacteriophages." These also are filter-passers and must be much smaller than the bacteria on which they prey, but whether they belong to the realm of chemistry of biology is still in dispute. Possibly the question may be settled in the end by finding that there is no definite dividing line between the two realms.